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## DEVELOPMENT OF AN INTERACTIVE COMPUTER PROGRAM TO PRODUCE BODY DESCRIPTION DATA

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AFAMRL-TR-83-058

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**FOR THE COMMANDER**



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## SUMMARY

Program GEBOD was developed in order to automate production of the body description portion of the ATB Model input deck. The ATB Model simulates the motion of the human body during dynamic events such as automobile crashes and aircraft cockpit ejections. It requires mass, center of gravity location, contact surface dimensions, principal moments of inertia and their associated directions for each of 15 body segments. Additionally, the ATB Model requires data locating the 14 joints that connect the body segments for body description.

The starting point for program GEBOD was a program written by Calspan Corporation named program GOOD, which was also designed to produce body description data for crash simulation models. A series of modifications and improvements to program GOOD resulted in program GEBOD. This report details those modifications and improvements.

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## PREFACE

Work described in this report was performed by the University of Dayton Research Institute (UDRI) under Contract No. F33615-81-C-0513. Principal investigator for UDRI was Mr. L. Douglas Baughman. Sponsor of the contract was the Modeling and Analysis Branch of the Air Force Aerospace Medical Research Laboratory (AFAMRL/BBM). Dr. Ints Kaleps (Chief, AFAMRL/BBM) acted as technical advisor for the work described in this report. The author would like to thank Mrs. Charlene Dunson of UDRI for her careful typing of this report.

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## GLOSSARY OF TERMS

**Anthropometry:** The study of human body dimensions.

**Axilla:** The arm pit.

**Iliocristale:** The most superior point on the rim of the pelvic bone.

**Inertial Properties:** The mass, center of gravity location, principal moments of inertia and associated directions of a body.

**Numerical Integration:** Approximating the value of an integral by arithmetic computations.

**Tenth Rib:** The lowest palpable rib in the mid-axillary line.

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## LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

- AFAMRL/BBM - Modeling and Analysis Branch of the Air Force Aerospace Research Laboratory.
- ATB Model - Articulated Total Body Model.
- CVS - Crash Victim Simulator.
- DD<sub>i</sub> - The i<sup>th</sup> measurement of the set of 32 body measurements used by both program GEBOD and program.
- GOOD - Generator Of Occupant Data.
- GEBOD - Generator Of Body Data.
- ROS - Revised Occupant Simulator.
- UDRI - University of Dayton Research Institute.

## SECTION 1 INTRODUCTION

The development of mathematical/computer models capable of predicting the motion of the human body in a dynamic environment has created a need for extensive data describing human geometry and inertial properties. These models have been used to predict body motion during events such as automobile crashes and aircraft cockpit ejections and are capable of pointing out potentially hazardous designs for these two environments. Various methods have been utilized to obtain the required body description data: predominantly the use of cadavers (eg., Chandler, et al., 1975 and Walker et al., 1973) and mathematically constructing geometric models of the human body (eg., Hanavan, 1964).

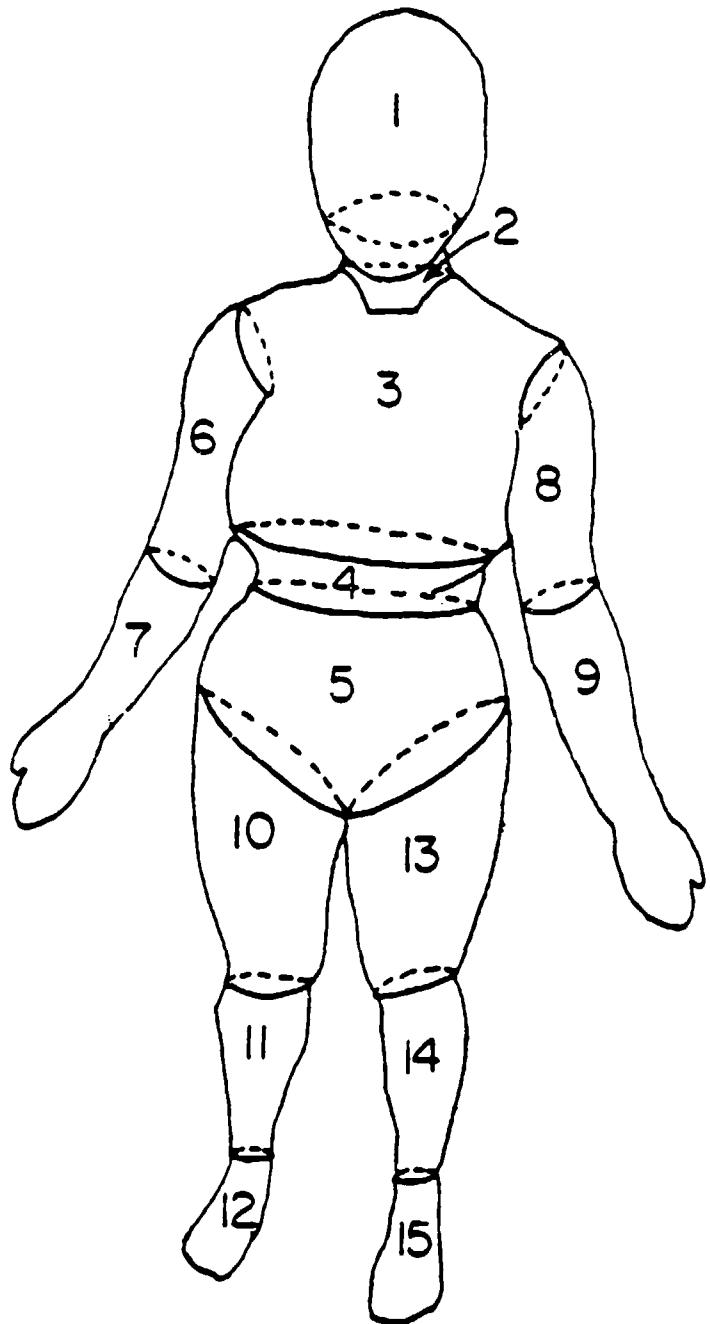
Calspan Corporation developed Program GOOD (Generator Of Occupant Data, Bartz and Gianotti, 1973) in order to automate the production of input data sets for the Crash Victim Simulator (CVS) Program (Bartz, 1971, also Fleck et al., 1975), and the Revised Occupant Simulator (ROS) Model (Segal, 1971). Both of these are computer programs developed by Calspan for the simulation of occupant dynamics during automobile crashes, the ROS Model in two dimensions, and the CVS Program in three-dimensions. The Articulated Total Body (ATB) Model (Fleck and Butler, 1975, also Butler and Fleck, 1980) was developed from the CVS Program, by incorporating modifications to provide the additional capabilities needed to simulate the various aspects of aircraft cockpit ejections. These modifications were performed by Calspan Corporation under the sponsorship of the Modeling and Analysis Branch of the Air Force Aerospace Medical Research Laboratory (AFAMRL/BBM), and were incorporated into the previous CVS Program as user available options.

The ATB Model performs simulations by viewing the human body as a series of connected rigid bodies, each referred to as a body segment. The ATB Model is flexible as to how many segments are used in modeling the human body. The standard configuration, presently being

used, consists of 15 segments, which is illustrated in Figure 1. For each of these body segments the ATB Model requires segment mass, principal moments of inertia, and semiaxes of an ellipsoid approximating the shape of the body segment. Also required are the locations of joints connecting the body segments.

The subject of this report is the development of an interactive computer program which will produce data sets for the ATB Model corresponding to specific types and sizes of human beings. This program has been named GEBOD (Generator of Body Data) and is an extensively modified version of Calspan's Program GOOD, with modifications being done by the University of Dayton Research Institute (UDRI). The changes made to Program GOOD in the development of GEBOD include the following:

1. an interactive format for the input of parameters describing the subject for which body description data is to be produced
2. body dimensions are obtained from regression equations instead of using a fixed percentile (see Appendix C)
3. restructuring the torso segments (thorax, abdomen, and pelvis)
4. development of a new technique for determining inertial properties of the torso and the feet segments
5. the units used for handling of data within the program were changed and allowance was made for results to be output in either metric or English units
6. format changes of the output making it compatible with the most recent version of the ATB Model.



- 1. Head
- 2. Neck
- 3. Thorax
- 4. Abdomen
- 5. Pelvis
- 6. Right Upper Arm
- 7. Right Lower Arm
- 8. Left Upper Arm
- 9. Left Lower Arm
- 10. Right Thigh
- 11. Right Calf
- 12. Right Foot
- 13. Left Thigh
- 14. Left Calf
- 15. Left Foot

Figure 1. Fifteen Segment Configuration Commonly Used With Articulated Total Body (ATB) Model.

## SECTION 2

### BODY DIMENSION SET

All the computations performed by Program GOOD are based on a set of 32 body measurements. These are used to determine sizes of body segments and the location of joints connecting them. GEBOD also uses this set of body measurements, which is listed in Table 1. Through the remainder of this report references to the  $i^{\text{th}}$  body measurement will be made as  $DD_i$ .

GEBOD has two ways of obtaining values for the required 32 body measurements. These measurements can either be read in from a disk file placed on the computer system by a user of GEBOD, or they can be generated by GEBOD using regression equations. There are three groups of regression equations stored within GEBOD. These groups correspond to possible subject types: adult male, adult female, or child. Within each group there are regression equations for each of the 32 body measurements. Both the adult male and the adult female groups contain three regression equations for each body measurement: one against height, one against weight, and the third a stepwise multiple regression equation against both height and weight. The child group contains four regression equations per body measurement: one against height, one against weight, one against age, and the fourth a stepwise multiple regression against height, weight and age. These different regression equations were developed to provide the user a flexible means for generating data sets.

All of the regression equations stored in GEBOD were computed from data in the AFAMRL Anthropometric Data Bank. A survey containing data on 2,420 male flying personnel of the U.S. Air Force (Grunhofer and Kroh, 1975) was used in the development of the adult male regression equations. For the adult female regressions a survey consisting of data on 1,905 women in the U.S. Air Force (Clauser, et al., 1972) was utilized. The child regression equations were computed from survey consisting of data on 3,782 children aged two to twenty years,

TABLE I  
CORRESPONDENCE BETWEEN 31 BODY DIMENSION USED AND THEIR SOURCES

<u>i</u>	<u>DIMENSION NAME</u>	<u>CHILDREN'S POPULATION</u>	<u>ADULT FEMALE POPULATION</u>	<u>ADULT MALE POPULATION</u>
-1	Age	L <sub>101</sub>	--	--
0	Weight	L <sub>1</sub>	L <sub>2</sub>	L <sub>2</sub>
1	Standing Height	L <sub>2</sub>	L <sub>7</sub>	L <sub>13</sub>
2	Shoulder Height	L <sub>61</sub>	L <sub>10</sub>	L <sub>15</sub>
3	Armpit Height	L <sub>62</sub>	L <sub>10</sub> - L <sub>53</sub> /π	L <sub>15</sub> - L <sub>103</sub> /π
4	Waist Height	L <sub>69</sub>	L <sub>13</sub>	L <sub>21</sub>
5	Seated Height	L <sub>9</sub>	L <sub>23</sub>	L <sub>32</sub>
6	Head Length	L <sub>20</sub>	L <sub>96</sub>	L <sub>150</sub>
7	Head Breadth	L <sub>19</sub>	L <sub>97</sub>	L <sub>156</sub>
8	Head to Chin Height	L <sub>25</sub>	L <sub>104</sub>	L <sub>179</sub>
9	Neck Circumference	L <sub>32</sub>	L <sub>36</sub>	L <sub>66</sub>
10	Shoulder Breadth	L <sub>36</sub>	L <sub>63</sub>	L <sub>50</sub>
11	Chest Depth	SEMI(L <sub>64</sub> , L <sub>63</sub> )	L <sub>74</sub>	L <sub>62</sub>
12	Chest Breadth	L <sub>64</sub>	L <sub>65</sub>	L <sub>52</sub>
13	Waist Depth	SEMI(L <sub>67</sub> , L <sub>66</sub> )	L <sub>75</sub>	L <sub>63</sub>
14	Waist Breadth	L <sub>67</sub>	L <sub>67</sub>	L <sub>53</sub>
15	Buttock Depth	SEMI(L <sub>72</sub> , L <sub>71</sub> )	L <sub>77</sub>	L <sub>64</sub>
16	Hip Breadth, Standing	L <sub>72</sub>	L <sub>68</sub>	L <sub>55</sub>
17	Shoulder to Elbow Length	L <sub>37</sub>	L <sub>31</sub>	L <sub>42</sub>
18	Forearm-Hand Length	L <sub>41</sub>	L <sub>32</sub> + L <sub>91</sub>	L <sub>44</sub> + L <sub>17</sub> - L <sub>18</sub>
19	Biceps Circumference	L <sub>39</sub>	L <sub>55</sub>	(L <sub>104</sub> + L <sub>105</sub> + L <sub>106</sub> + L <sub>107</sub> )/4
20	Elbow Circumference	L <sub>43</sub>	L <sub>59</sub>	L <sub>109</sub>
21	Forearm Circumference	L <sub>43</sub>	L <sub>60</sub>	L <sub>110</sub>
22	Wrist Circumference	L <sub>45</sub>	L <sub>62</sub>	L <sub>112</sub>
23	Knee Height, Seated	L <sub>15</sub>	L <sub>18</sub> + L <sub>46</sub> /(2π)	L <sub>37</sub>
24	Thigh Circumference	L <sub>77</sub>	L <sub>45</sub>	L <sub>96</sub>
25	Upper Leg Circumference	(L <sub>77</sub> + L <sub>81</sub> )/2	(L <sub>45</sub> + L <sub>46</sub> )/2	L <sub>98</sub>
26	Knee Circumference	(L <sub>77</sub> + L <sub>81</sub> )/2	L <sub>46</sub>	L <sub>99</sub>
27	Calf Circumference	L <sub>81</sub>	L <sub>47</sub>	L <sub>100</sub>
28	Ankle Circumference	L <sub>83</sub>	L <sub>49</sub>	L <sub>102</sub>
29	Ankle Height, Outside	L <sub>85</sub>	L <sub>21</sub>	L <sub>31</sub>
30	Foot Breadth	L <sub>87</sub>	L <sub>95</sub>	L <sub>127</sub>
31	Foot Length	L <sub>86</sub>	L <sub>94</sub>	L <sub>125</sub>

NOTE:

- 1) L<sub>i</sub> refers to the i<sup>th</sup> dimension of the appropriate anthropometric survey.
- 2) SEMI(a, b) is a function returning one axis length of an ellipse where b is the circumference of the ellipse, and a is its other axis length.

from throughout the United States (Synder, et al., 1977). In the case of the child regression equations, some of the regressions were based on data pertaining to only a subset of the total population.

None of the three anthropometric surveys used included all of the measurements needed. In those cases where a needed measurement was missing from a survey it was approximated from available measurements. Table 1 lists the measurements actually used from each survey and indicates any approximations made. Appendix D gives a complete listing of the regression equations computed.

### SECTION 3

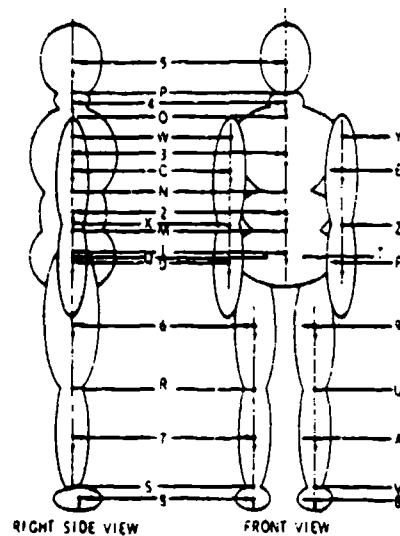
#### BODY GEOMETRY

The structure and appearance of the human model as depicted by the ATB Model is determined from contact ellipsoid semiaxes and joint locations. A contact ellipsoid is associated with each body segment, giving the segment shape and providing an interaction surface between the segment and its environment. The joints connect segments and serve as pivot points about which rotational motion is allowed.

A joint is located relative to the two segments it connects (see Table 2). For example, the elbow joint is located by two sets of three-dimensional coordinates: one set relative to the local reference system of the upper arm; the other relative to the local reference system of the forearm. Local reference systems (also referred to as segment geometric axis systems) are located at each segment's center of mass with an arbitrary orientation. The orientation of each of these axis systems, relative to the geometry of its segment, may be chosen so as to provide maximum convenience in inputting data items to the ATB Model.

Each local reference axis system is fixed within its segment, and thus changes orientation as the orientation of its segment is changed. For use with GEBOD the local reference axis systems have been chosen so that they all have a common orientation when the model is an erect standing position, arms extended downward, and toes pointed straight down. When the segments are positioned as described the X axis of each local reference system points forward, each Y to the right, and each Z downward, all relative to the model (see Figure 2).

GEBOD computes joint locations by use of the expressions listed in Table 2. These expressions were developed by using the geometric center of each segment (the geometric center of a segment is the center of that segment's contact ellipsoid) as an approximation for its



LEGEND:

LOCAL REFERENCE SYSTEM ORIGINS

- 1 - PELVIS
- 2 - ABDOMEN
- 3 - THORAX
- 4 - NECK
- 5 - HEAD
- 6 - RIGHT THIGH
- 7 - RIGHT CALF
- 8 - RIGHT FOOT
- 9 - LEFT THIGH
- A - LEFT CALF
- B - LEFT FOOT
- C - RIGHT UPPER ARM
- D - RIGHT FORE ARM
- E - LEFT UPPER ARM
- F - LEFT FORE ARM

JOINTS

- M - ABDOMEN-PELVIS
- N - THORAX-ABDOMEN
- O - NECK-THORAX
- P - HEAD-NECK
- Q - RIGHT HIP
- R - RIGHT KNEE
- S - RIGHT ANKLE
- T - LEFT HIP
- U - LEFT KNEE
- V - LEFT ANKLE
- W - RIGHT SHOULDER
- X - RIGHT ELBOW
- Y - LEFT SHOULDER
- Z - LEFT ELBOW

NOTES:

1. EXCEPT IN THE CASE OF THE FEET THE LOCAL REFERENCE AXES ARE LABELED AS FOLLOWS:
  - A. ALL VERTICAL AXES ARE Z AXES
  - B. ALL HORIZONTAL AXES IN THE FRONT VIEW ARE Y AXES
  - C. ALL HORIZONTAL AXES IN THE RIGHT SIDE VIEW ARE X AXES
2. IN THE CASE OF THE FEET THE LOCAL REFERENCE AXES ARE LABELED AS FOLLOWS:
  - A. ALL VERTICAL AXES ARE X AXES
  - B. BOTH HORIZONTAL AXES IN THE FRONT VIEW ARE Y AXES
  - C. THE HORIZONTAL AXIS IN THE RIGHT SIDE VIEW IS THE Z AXIS
3. IN THE RIGHT SIDE VIEW ONLY LIMB SEGMENTS ON THE RIGHT SIDE OF THE BODY ARE SHOWN

Figure 2. Local Reference Axis Systems and Joint Locations Used By GEBOD to Prepare Input Data for the ATB Model.

center of gravity. Joint coordinates computed using these expressions, then, are not actually relative to segment local reference systems, but to a parallel set of axes located at the geometric center. Once GEBOD has computed the true location of the segment centers of gravity, the appropriate translation is applied to convert to the true local reference systems.

Relative to the segment axis systems described it has been possible to make certain assumptions, simplifying the development of the expressions for joint locations listed in Table 2. First, the X coordinate of all joints relative to appropriate local reference systems, with the exception of the ankles relative to the feet, are zero. Secondly, it is assumed that the only joints with non-zero Y local reference coordinates are the shoulders relative to the thorax and the hips relative to the pelvis (see Figure 2).

Using all the assumptions mentioned the expressions for joint locations as functions of body dimensions were developed, and are listed in Table 2. Similarly, expressions for contact ellipsoid semi-axes are listed in Table 3. Many of these expressions are very straightforward and in many cases have been taken directly from Program GOOD. Others, however, are more complicated and require further explanation.

### 3.1 DETERMINING EXPRESSIONS FOR JOINT LOCATIONS AND SEMIAxes OF TORSO SEGMENTS

The way in which the torso is divided into three segments is somewhat arbitrary and has varied over the time that the CVS Program and the ATB Model have been in existence. Program GOOD produces data describing an upper torso that only extends down to the axilla area, with the mid torso then extending from the axilla down to the waist. Present usage of the ATB model defines the mid torso or abdomen as extending from the tenth rib landmark to the iliocristale landmark, with the thorax being all of the torso above, and the pelvis being all of the torso below. Because of this change in the definition of torso segments, joint locations and semiaxes lengths were changed from those given by Program GOOD for the torso.

TABLE 2  
JOINT LOCATIONS RELATIVE TO LOCAL REFERENCE AXIS SYSTEMS

<u>JOINT</u>	<u>RELATIVE TO</u>	<u>X</u>	<u>Y</u>	<u>LOCATION</u>
Abdomen-pelvis	pelvis	0.0	0.0	$(DD_1 - DD_5 - DD_4 + 0.1(DD_2 - DD_4))/2$
	abdomen	0.0	0.0	$(DD_2 - DD_4)/10$
Thorax-abdomen	abdomen	0.0	0.0	$-(DD_2 - DD_4)/10$
	thorax	0.0	0.0	$9(DD_2 - DD_4)/20$
Neck-thorax	thorax	0.0	0.0	$-9(DD_2 - DD_4)/20$
	neck	0.0	0.0	$(DD_1 - DD_8 - DD_2 - \frac{DD_9}{2\pi})/2$
Head-neck	neck	0.0	0.0	$-(DD_1 - DD_8 - DD_2 - \frac{DD_9}{2\pi})/2$
	head	0.0	0.0	$(DD_8 + \frac{DD_9}{2\pi})/2$
Right hip	pelvis	0.0	$(DD_{16} - \frac{DD_{24}}{\pi})/2$	$(DD_4 - (DD_2 - DD_4)/10 - DD_1 + DD_5 - \frac{DD_{24}}{\pi})/2$
	right thigh	0.0	0.0	$-(DD_1 - DD_5 - DD_{23} + \frac{DD_{26}}{\pi})/2$
Right knee	right thigh	0.0	0.0	$(DD_1 - DD_5 - DD_{23} + \frac{DD_{24}}{\pi})/2$
	right calf	0.0	0.0	$-(DD_{23} - DD_{29} + \frac{DD_{28}}{2\pi} - \frac{DD_{26}}{\pi})/2$
Right ankle	right calf	0.0	0.0	$(DD_{23} - DD_{29} - \frac{DD_{28}}{2\pi})/2$
	right foot	$\frac{DD_{29}}{2}$	0.0	$-(DD_{31} - \frac{DD_{28}}{\pi})/2$
Left hip	pelvis	0.0	$-(DD_{16} - \frac{DD_{24}}{\pi})/2$	$(DD_4 - (DD_2 - DD_4)/10 - DD_1 + DD_5 - \frac{DD_{24}}{\pi})/2$
	left thigh	0.0	0.0	$-(DD_1 - DD_5 - DD_{23} + \frac{DD_{26}}{\pi})/2$
Left knee	left thigh	0.0	0.0	$(DD_1 - DD_5 - DD_{23} + \frac{DD_{24}}{\pi})/2$
	left calf	0.0	0.0	$-(DD_{23} - DD_{29} + \frac{DD_{28}}{2\pi} - \frac{DD_{26}}{\pi})/2$
Left ankle	left calf	0.0	0.0	$(DD_{23} - DD_{29} - \frac{DD_{28}}{2\pi})/2$
	left foot	$\frac{DD_{29}}{2}$	0.0	$-(DD_{31} - \frac{DD_{28}}{\pi})/2$
Right shoulder	thorax	0.0	$(DD_{10} - \frac{DD_{19}}{\pi})/2$	$-(DD_2 - DD_3 - \frac{DD_{19}}{2\pi})$
	right upper arm	0.0	0.0	$-(DD_{17} - \frac{DD_{19}}{\pi})/2$
Right elbow	right upper arm	0.0	0.0	$(DD_{17} - \frac{DD_{20}}{\pi})/2$
	right forearm	0.0	0.0	$-(DD_{18} - \frac{DD_{20}}{\pi})/2$

TABLE 2 (Continued)

Left shoulder	thorax	0.0	$-(DD_{10} - \frac{DD_{19}}{\pi})/2$	$-(DD_2 - DD_3 - \frac{DD_{19}}{2\pi})$
	left upper arm	0.0	0.0	$-(DD_{17} - \frac{DD_{19}}{\pi})/2$
Left elbow	left upper arm	0.0	0.0	$(DD_{17} - \frac{DD_{20}}{\pi})/2$
	left forearm	0.0	0.0	$-(DD_{18} - \frac{DD_{20}}{\pi})/2$

TABLE 3  
CONTACT ELLIPSOID SEMIAxes

<u>SEGMENT</u>	<u>X SEMIAxis</u>	<u>Y SEMIAxis</u>	<u>Z SEMIAxis</u>
Pelvis	$\frac{DD_{15}}{2}$	$\frac{DD_{16}}{2}$	$(DD_4 + DD_5 - DD_1 - 0.1(DD_2 - DD_4)) / 2$
Abdomen	$\frac{DD_{13}}{2}$	$\frac{DD_{14}}{2}$	$(DD_2 - DD_4) / 10 + \frac{DD_9}{2}$
Thorax	$\frac{DD_{11}}{2}$	$\frac{DD_{12}}{2}$	$.45(DD_2 - DD_4)$
Neck	$\frac{DD_9}{2\pi}$	$\frac{DD_9}{2\pi}$	$(DD_1 - DD_8 - DD_2 + \frac{DD_9}{2\pi}) / 2$
Head	$\frac{DD_6}{2}$	$\frac{DD_7}{2}$	$(DD_8 + \frac{DD_9}{2\pi}) / 2$
Right and Left Thigh	$\frac{DD_{24} + DD_{25}}{4\pi}$	$\frac{DD_{24} + DD_{25}}{4\pi}$	$(DD_1 - DD_5 - DD_{23} + \frac{DD_{24} + DD_{26}}{\pi}) / 2$
Right and Left Calf	$\frac{DD_{27}}{2\pi}$	$\frac{DD_{27}}{2\pi}$	$(DD_{23} - DD_{29} + \frac{DD_{28}}{2\pi}) / 2$
Right and Left Foot	$\frac{DD_{29}}{2}$	$\frac{DD_{30}}{2}$	$\frac{DD_{31}}{2}$
Right and Left Upper Arm	$\frac{DD_{19}}{2\pi}$	$\frac{DD_{19}}{2\pi}$	$\frac{DD_{17}}{2}$
Right and Left Forearm	$\frac{DD_{21}}{2\pi}$	$\frac{DD_{21}}{2\pi}$	$\frac{DD_{18}}{2}$

Since none of the 32 body measurements being used give tenth rib height, the landmarks located in the two stereophotometric studies (Baughman, 1981 and McConville et al., 1980) were examined. It was found that the ratio of thorax height (vertical distance between suprasternale and tenth rib midspine) to abdomen height (vertical distance between tenth rib midspine and right iliocristale) averages about 4:1. Using this result the distance between the thorax-abdomen joint and the abdomen-pelvis height was set to be one-fifth of the difference between shoulder height and waist height  $[(DD_2 - DD_4)/5]$ .

When developing the expressions for torso joint locations, these locations were first laid out in a global setting, with axes origin on the floor (that is vertical distance from the floor). The top of the thorax was determined by shoulder height ( $DD_2$ ), and the distance from the floor to the bottom of the pelvis was taken as the difference between standing height and seated height ( $DD_1 - DD_5$ ). The center of the abdomen was then located by waist height ( $DD_4$ ). The abdomen-pelvis joint and the thorax-abdomen joint were located so that the center of the abdomen is mid-way between these two joints (recall that the distance between these two joints is  $[(DD_2 - DD_4)/5]$ ). The center of the thorax was then placed mid-way between the thorax abdomen joint and top of the torso, and the center of the pelvis was placed mid-way between the bottom of the pelvis and the abdomen-pelvis joint. From these global locations the expressions for local reference system coordinates of torso joints were determined.

The Z semiaxis of the pelvis contact ellipsoid is set to the distance from center of the pelvis to the abdomen-pelvis joint. This causes the pelvis contact ellipsoid to cover the pelvis vertically from the abdomen-pelvis joint to the bottom of the pelvis ( $DD_1 - DD_5$ ), since the pelvis center is mid-way between these points. Similarly, the Z semiaxis of the thorax contact ellipsoid is set to the distance from center of the thorax to the thorax-abdomen joint, which results in the contact ellipsoid covering the thorax from the top of the thorax ( $DD_2$ ) to the thorax-abdomen joint. For the resulting model to

have a proper appearance there must be some overlap between adjacent contact ellipsoids. Since this overlap is primarily for appearance, the extent of overlap utilized is the neck radius ( $DD_{2g}/2\pi$ ). This is the amount that the abdomen contact ellipsoid overlaps both the thorax contact ellipsoid and the pelvis contact ellipsoid.

### 3.2 DETERMINING EXPRESSIONS FOR JOINT LOCATIONS AND SEMIAxes OF THE HEAD AND NECK

As in the torso, segment centers and joint locations involving the head and neck were first laid out globally. First, the top of the head was placed at standing height ( $DD_1$ ), and the neck-thorax joint was placed at shoulder height ( $DD_2$ ). In order to provide overlap the Z semiaxis of the head is set to one half the quantity head height plus neck radius

$$[(DD_8 + \frac{DD_9}{2\pi})/2].$$

The center of the head is then determined by standing height minus the Z semiaxis of the head, and the head-neck joint is located by standing height minus twice the Z semiaxis of the head. The center of the neck is located mid-way between the head-neck joint and the neck-thorax joint. The top of the neck contact ellipsoid is desired to be at standing height minus head height ( $DD_1 - DD_8$ ), so the Z semiaxis of the neck contact ellipsoid is set to the distance between this location and the center of the neck.

### 3.3 DETERMINING EXPRESSIONS FOR ANKLE LOCATIONS RELATIVE TO THE FEET

As with other limb segments, the Z reference axis of either foot runs the length of the segment (from heel to toe, see Figure 2). For simplicity in developing expression for joint locations, the foot is viewed in a normal position for a standing model. This rotates the foot reference system  $90^\circ$  from the reference system of other systems, i.e. Z forward, X upward, and Y to the right. The ankle joint is then

a vertical distance of ankle height ( $DD_{29}$ ) from the bottom of the foot, or one half this distance from the center of the foot. In the z-horizontal direction the ankle joint is located as being ankle radius ( $DD_{29}/2\pi$ ) in front of the back of the foot, and the center of the foot is located at one-half foot length ( $DD_{31}/2$ ) from the back of the foot in this direction.

### 3.4 DETERMINING EXPRESSIONS FOR JOINT LOCATIONS AND SEMIAxes OF LIMB SEGMENTS

The remainder of the joint and semiaxis expressions were taken directly from Program GOOD. A concept used in developing expressions for many of these semiaxes and joint locations is that of spherical joints. The usage of this concept is illustrated in Figure 3.

### 3.5 CONCLUSION

Using the criteria discussed, the expressions in Table 2 for joint locations and the expressions in Table 3 for contact ellipsoid semiaxes have been developed. When used with a set of the 32 body dimensions corresponding to a subject of a specific type and size, these expressions provide values necessary to determine the structure and appearance of the human model utilized by the ATB Model.

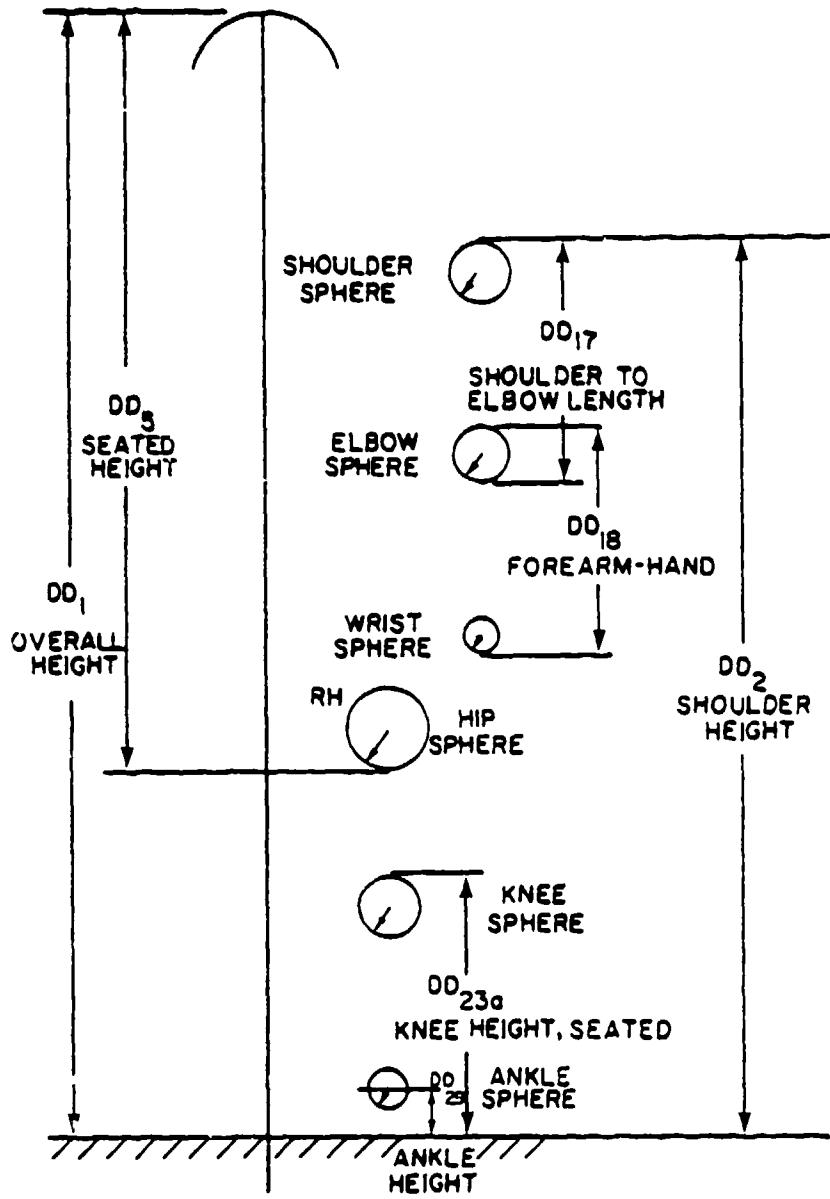


Figure 3. Spherical Joint Concept Developed for Program GOOD and Used to Determine Joint Locations Relative to Limb Segments.

Radii of these spheres are as follows:

Shoulder Sphere	$DD_{19}/(2\pi)$
Elbow Sphere	$DD_{20}/(2\pi)$
Wrist Sphere	$DD_{22}/(2\pi)$
Hip Sphere	$DD_{24}/(2\pi)$
Knee Sphere	$DD_{26}/(2\pi)$
Ankle Sphere	$DD_{28}/(2\pi)$

SECTION 4  
INERTIAL PROPERTIES OF BODY SEGMENTS

The inertial properties of a body refer to its mass, principal moments of inertia and associated directions, and the location of its center of gravity. The ATB Model requires direct input of the mass and principal moments of inertia of each segment, as well as the directions of the principal moments, relative to the local reference axes. Use of local reference axis systems, which are located with respect to segment centers of gravity, to specify joint locations indirectly locate the segment centers of gravity. Thus, direct input of center of gravity locations to the ATB Model is not necessary.

The distribution of mass within the human body greatly affects the inertial properties. For simplicity it is assumed that the human body is homogeneous, and thus, each individual body segment is homogeneous and has the same density as does all the other body segments.

Program GOOD determines inertial properties of a segment by calculating the inertial properties of that segment's contact ellipsoid (see Appendix E). These inertial properties are then taken as approximations to the inertial properties of the segment. The density used in these computations is determined by first computing the volume of all the contact ellipsoids combined. From this total a density may be determined such that the mass of all the segments combined will equal the desired total mass of the body ( $DD_0$ ).

Program GEBOD also uses this technique for computation of inertial properties of the head, neck, upper and forearms, and thighs and calves. For the torso segments and the feet GEBOD uses a technique similar to that developed by Leet (1978). This involves modeling a segment by a right elliptical solid that satisfies two criteria:

- 1) each horizontal cross section (parallel to the local reference XY plane) is an ellipse,
- 2) the center of each of these elliptical cross sections lies on the Z local reference axis.

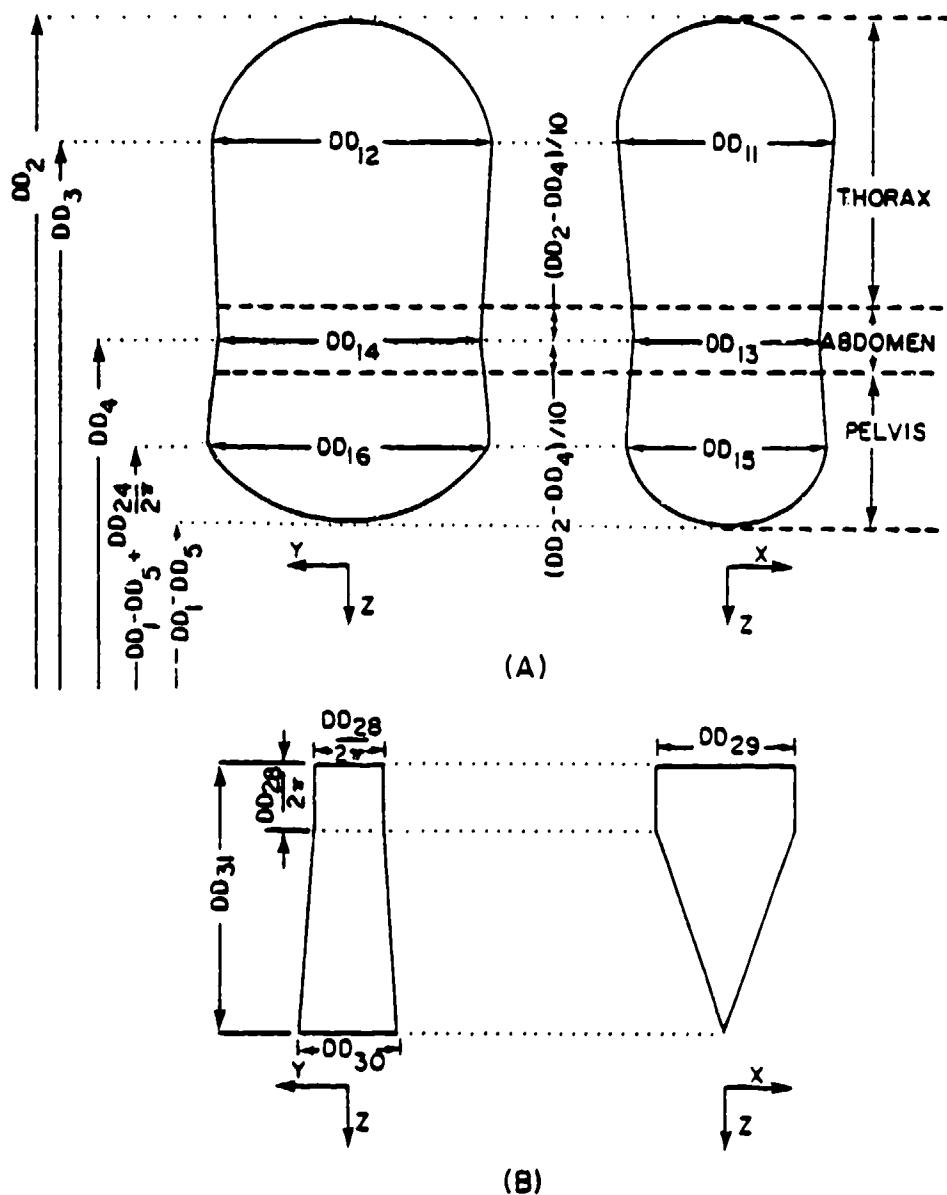
The inertial properties of this model are then calculated and taken as approximations to the inertial properties of the segment.

The right elliptical solid used for the torso segments is illustrated in Figure 4a. It consists of four pieces. The top is a semi-ellipsoid. Below this are two elliptical frustums. The bottom of the model consists of another semi-ellipsoid. The right and left feet use identical models which are elliptical frustums. The dimensions of the frustums and ellipsoids used in these models are determined from the body dimension data as indicated in Figures 4a and 4b.

Numerical integration is used to compute inertial properties of the right elliptical solids. Successive approximations are made to the model by stacks of elliptical cylinders. Within each approximation all cylinders are of the same height. Each successive approximation uses more cylinders of a lesser height than the previous. After each approximation the combined volume of all cylinders within the stack is compared back to the combined volume of the previous stack. When the difference between these two volumes drops below a specified tolerance level, the inertial properties of the combined stack of cylinders (see Appendix E) are taken as the inertial properties of the right elliptical solid. These inertial properties are then used as approximations to the inertial properties of the segment in question.

Program GEBOD determines the density to be used in computation of inertial properties in much the same way as does Program GOOD. The combined volume of all models used to determine inertial properties (both ellipsoids and right elliptical solids) is computed and a density is determined so that the total mass of these models will equal the desired total body mass ( $DD_0$ ). The ratio of this density to the density of water (which approximates average human body density) is listed with other results of Program GEBOD as a weight correction factor.

The center of gravity of the models used to approximate segment inertial properties are taken by GEBOD as the true locations of segment centers of gravity. In developing expressions for joint



**Figure 4.** Cross Sections of Right Elliptical Solids Used to Approximate Segment Inertial Properties.

- (a) Solid used with thorax segments.
- (b) Solid used with feet segments.

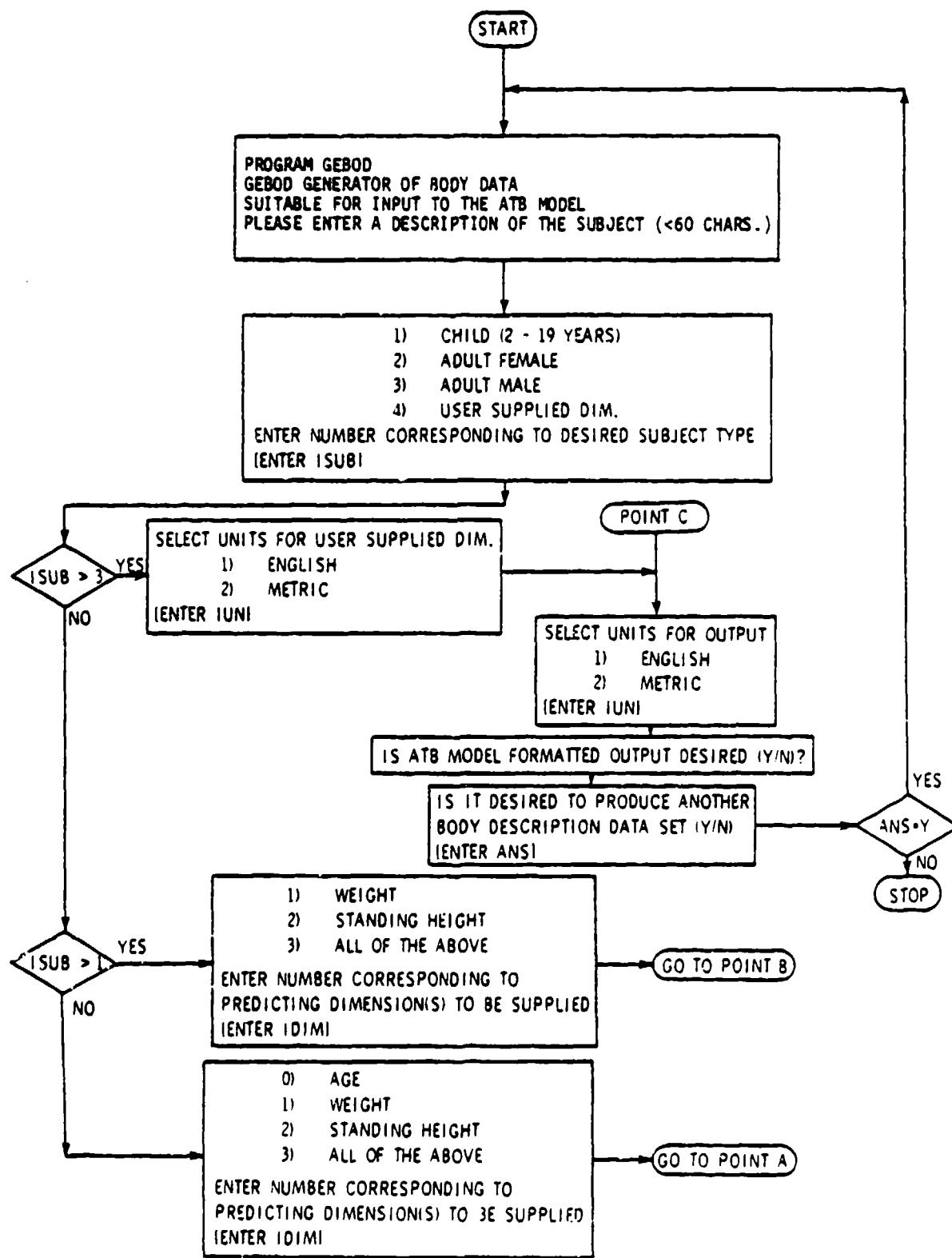
locations (see Section 3), the origins of local reference systems (i.e., segment centers of gravity) were approximated by contact ellipsoid centers. Once GEBOD has developed the models for inertial properties joint location coordinates must be converted, corresponding in each case to a translation of axes from a contact ellipsoid center to the center of gravity of the model used to compute inertial properties. Since an ellipsoid is completely symmetrical, its center of gravity is located at its center, which agrees with the assumed location of the local reference systems. The right elliptical solids, however, are only symmetric about the Z axis. So, in general, the location of the center of gravity of this model does not correspond with its center in the Z direction. The torso segments and feet segments, which use this type model in computation of their inertial properties, are the only segments in which the center of gravity does not coincide with the center of the contact ellipsoid. Because this moves the location of the local reference system of these segments in the Z direction, the Z coordinates of joints located relative to these segments are adjusted for this change, after computation of inertial properties. This adjustment of joint Z coordinates completes the computations performed by GEBOD in order to determine body description data.

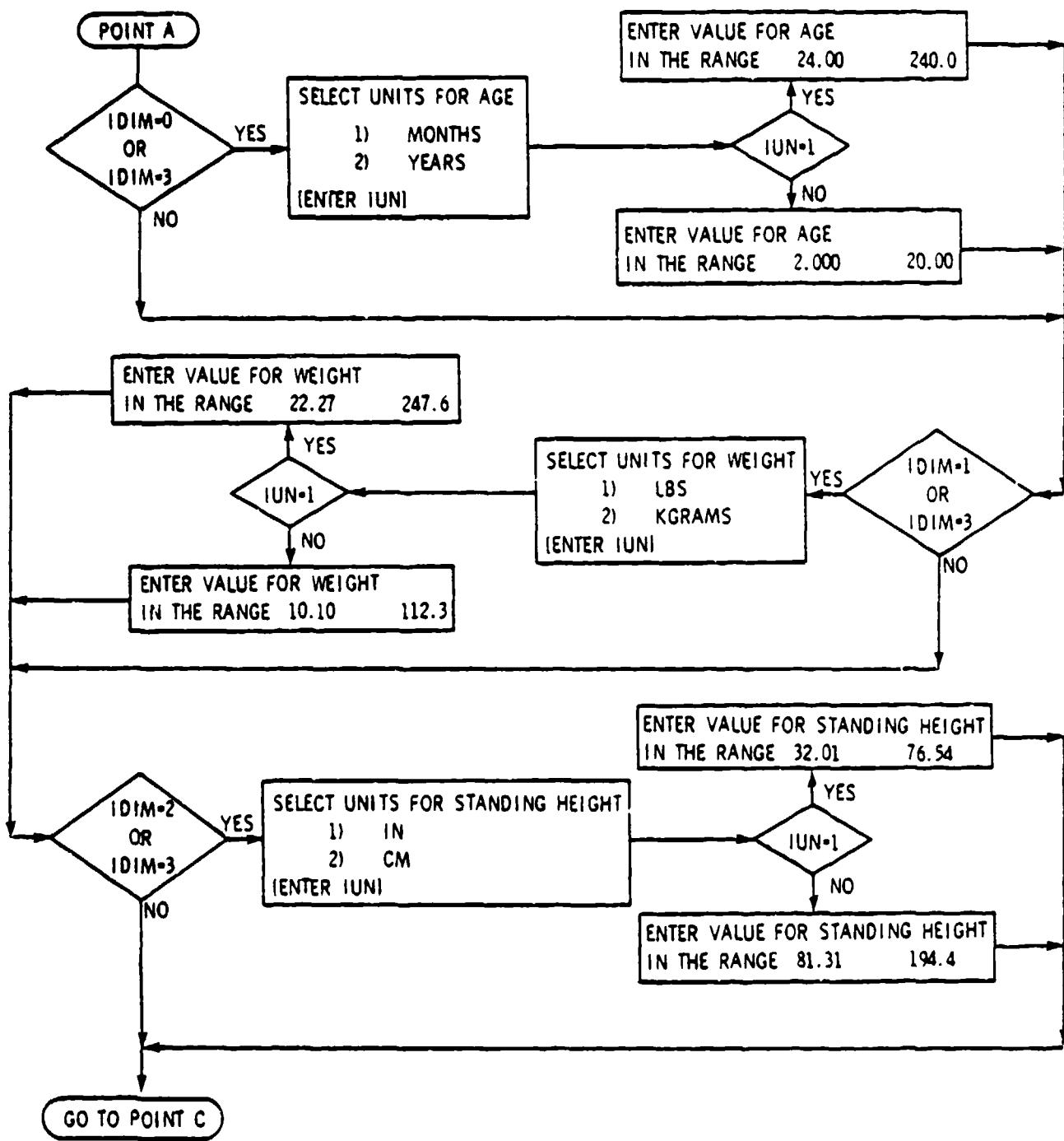
## APPENDIX A USER'S GUIDE

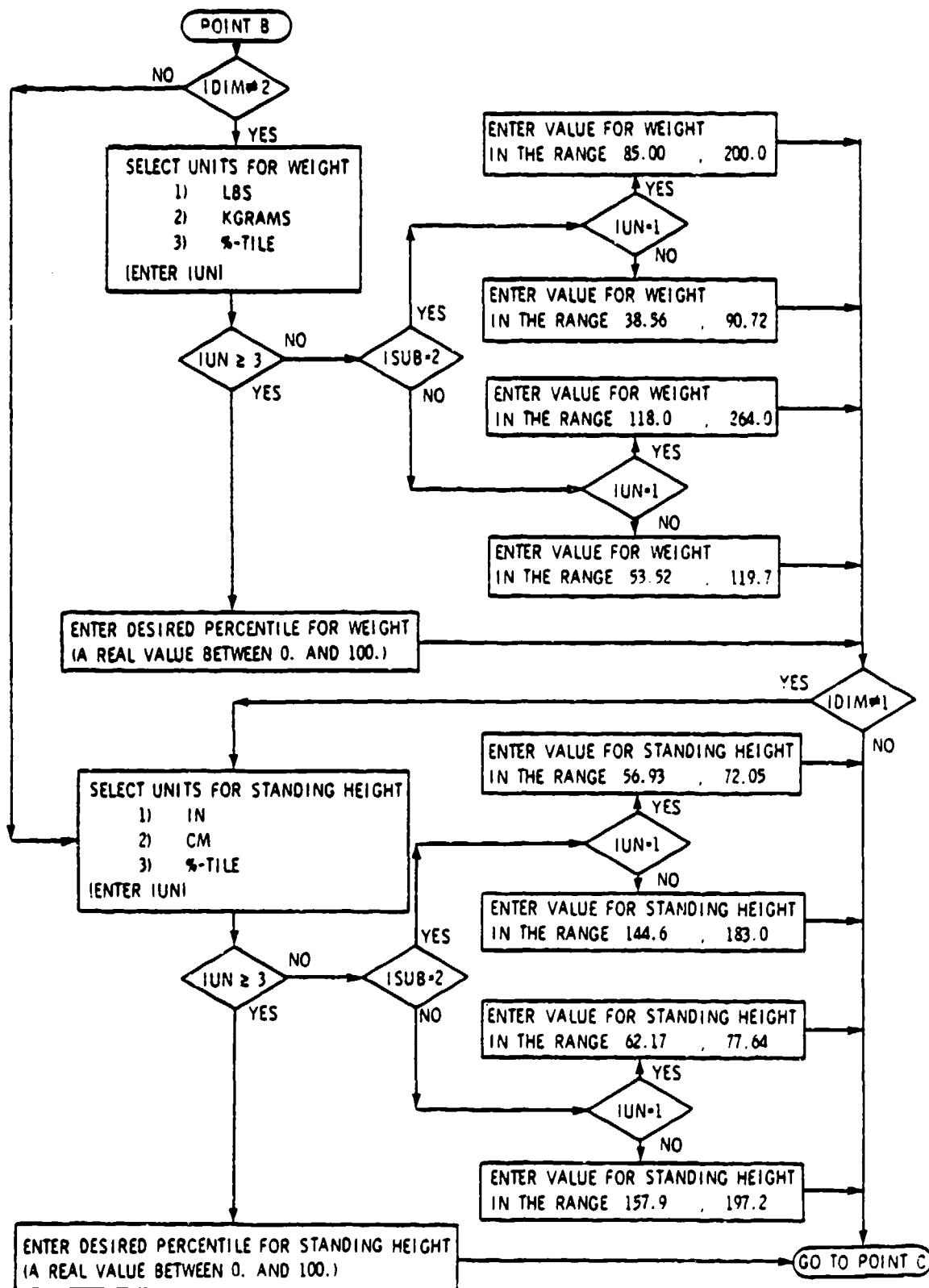
The computer program GEBOD was written in Perkin-Elmer Fortran VII and was developed and tested on the Perkin-Elmer 3240 located at Building 441, Wright-Patterson Air Force Base; Dayton, Ohio. This version of the Fortran VII programming language meets the ANSI '77 standard for Fortran, and thus, GEBOD should be portable to any system supporting an ANSI '77 standard Fortran.

GEBOD utilizes five logical units. Prompts for the user are written to logical unit 5. User input is received through unit 7. Body description data produced by GEBOD is written to both units 3 and 9. Data written to unit 3 is ready for insertion into the ATB Model input deck, whereas the data written to unit 9 (see Appendix B), is a tabular presentation of the data. If the user chooses to supply a specific set of the 32 body dimensions (see Table 1), this data is received through unit 1. The data must be supplied in four 80 character records, each record containing values for 8 of the body measurements. The values for the body measurements are listed in sequential order on these records with each record using an (8F10.3) format.

The remainder of this appendix is a flowchart describing options available to the user of GEBOD.







APPENDIX B  
SAMPLE OUTPUT FROM PROGRAM GEBOD

TEST OF 5'10" MALE WEIGHING 150LB.

ADULT MALE

SELECTED BODY DIMENSIONS

	WEIGHT	150.0	LBS
	STANDING HEIGHT	70.00	IN

COMPUTED BODY DIMENSIONS

O	WEIGHT	68.04	KGRAMS
1	STANDING HEIGHT	177.8	CM
2	SHOULDER HEIGHT	145.1	CM
3	ARMPIT HEIGHT	130.4	CM
4	WAIST HEIGHT	107.2	CM
5	SEATED HEIGHT	93.12	CM
6	HEAD LENGTH	19.74	CM
7	HEAD BREADTH	15.42	CM
8	HEAD TO CHIN HEIGHT	22.79	CM
9	NECK CIRCUMFERENCE	36.63	CM
10	SHOULDER BREADTH	40.01	CM
11	CHEST DEPTH	22.58	CM
12	CHEST BREADTH	30.80	CM
13	WAIST DEPTH	20.03	CM
14	WAIST BREADTH	28.39	CM
15	BUTTOCK DEPTH	21.75	CM
16	HIP BREADTH, STANDING	33.59	CM
17	SHOULDER TO ELBOW LENGTH	36.05	CM
18	FOREARM-HAND LENGTH	49.41	CM
19	BICEPS CIRCUMFERENCE	29.01	CM
20	ELBOW CIRCUMFERENCE	30.19	CM
21	FOREARM CIRCUMFERENCE	26.74	CM
22	WRIST CIRCUMFERENCE	17.03	CM
23	KNEE HEIGHT, SEATED	55.61	CM
24	THIGH CIRCUMFERENCE	53.79	CM
25	UPPER LEG CIRCUMFERENCE	36.74	CM
26	KNEE CIRCUMFERENCE	37.30	CM
27	CALF CIRCUMFERENCE	34.92	CM
28	ANKLE CIRCUMFERENCE	21.41	CM
29	ANKLE HEIGHT, OUTSIDE	13.83	CM
30	FOOT BREADTH	9.601	CM
31	FOOT LENGTH	26.88	CM

WEIGHT CORRECTION FACTOR = 1.110

## TEST OF 5'10" MALE WEIGHING 150LB.

## CRASH VICTIM PARAMETERS (3-D)

NO.	SYN PLOT	SEGMENT MASS (KG.)	SEGMENT MOMENT OF INERTIA (KG-M <sup>2</sup> )			SEGMENT CONTACT ELLIPSOID SEMIAxis (CM)			SEGMENT CENTER (CM)		
			X	Y	Z	X	Y	Z	X	Y	Z
1	L1	11.369	0.10929	0.06579	0.10943	10.69	16.79	9.37	0.00	0.00	-0.28
2	CT 2	3.856	0.02210	0.01164	0.03018	10.01	14.20	9.62	0.00	0.00	-0.02
3	UT 3	16.797	0.21751	0.17534	0.13616	11.29	15.40	17.04	0.00	0.00	-1.76
4	N 4	1.244	0.00241	0.00241	0.00170	5.83	5.83	7.88	0.00	0.00	0.00
5	H 5	5.062	0.02696	0.03064	0.01601	9.87	7.71	14.31	0.00	0.00	0.00
6	RUL 6	7.004	0.12632	0.12632	0.01465	7.20	7.20	29.03	0.00	0.00	0.00
7	RLL 7	3.243	0.03539	0.03539	0.00404	5.56	5.56	22.59	0.00	0.00	0.00
8	RF 8	0.737	0.00337	0.00326	0.00040	6.91	4.80	13.44	0.00	0.00	3.46
9	LUL 9	7.004	0.12632	0.12632	0.01465	7.20	7.20	29.03	0.00	0.00	0.00
10	LLL 10	3.243	0.03539	0.03539	0.00404	5.56	5.56	22.59	0.00	0.00	0.00
11	LF B	0.397	0.00337	0.00326	0.00040	6.91	4.60	13.44	0.00	0.00	3.46
12	RUA C	1.795	0.01246	0.01246	0.00153	4.62	4.62	18.03	0.00	0.00	0.00
13	RLA D	2.080	0.02634	0.02634	0.00152	4.26	4.26	24.71	0.00	0.00	0.00
14	LUA E	1.795	0.01246	0.01246	0.00153	4.62	4.62	18.03	0.00	0.00	0.00
15	LLA F	2.080	0.02634	0.02634	0.00152	4.26	4.26	24.71	0.00	0.00	0.00

JOINT J	SYN PLOT	JNT PIN	LOCATION(CM) - SEG(j+1)			LOCATION(CM) - SEG(j)			PRIM. AXIS(DEG) - SEG(j+1)			PRIM. AXIS(DEG) - SEG(j)		
			X	Y	Z	X	Y	Z	YAW	PITCH	ROLL	YAW	PITCH	ROLL
1	P	1 0	0.00	0.00	-9.65	0.00	0.00	3.76	0.00	30.00	0.00	0.00	0.00	0.00
2	M	2 0	0.00	0.00	-3.81	0.00	0.00	15.26	0.00	0.00	0.00	0.00	0.00	0.00
3	NP	0 3	0.00	0.00	-18.83	0.00	0.00	2.05	0.00	0.00	0.00	0.00	0.00	0.00
4	NP	4 0	0.00	0.00	-2.05	0.00	0.00	14.31	0.00	30.00	0.00	0.00	0.00	0.00
5	RH	0 1	0.00	8.23	0.53	0.00	0.00	-20.47	0.00	0.00	0.00	-90.00	0.00	0.00
6	RK	6 1	0.00	23.10	0.00	0.00	0.00	-16.66	0.00	90.00	0.00	-45.00	0.00	0.00
7	RA	5 7 0	0.00	19.19	6.91	0.00	-6.57	0.00	45.00	0.00	0.00	-90.00	0.00	0.00
8	LH	7 1 0	0.00	-9.23	0.53	0.00	0.00	-20.47	0.00	0.00	0.00	-90.00	0.00	0.00
9	LK	9 1	0.00	23.10	0.00	0.00	-16.66	0.00	90.00	0.00	-45.00	0.00	0.00	0.00
10	LA	10 0	0.00	19.19	6.91	0.00	-6.57	0.00	45.00	0.00	0.00	-90.00	0.00	0.00
11	RC	8 3 0	0.00	15.39	-11.91	0.00	0.00	-13.41	0.00	0.00	0.00	15.00	0.00	0.00
12	RE	X 12 1	0.00	13.22	0.00	0.00	-19.90	0.00	60.00	0.00	0.00	0.00	0.00	0.00
13	LS	Y 3 0	0.00	-15.39	-11.91	0.00	0.00	-13.41	0.00	0.00	0.00	15.00	0.00	0.00
14	LE	Z 14 1	0.00	13.22	0.00	0.00	-19.90	0.00	60.00	0.00	0.00	0.00	0.00	0.00

APPENDIX C  
COMPARISON OF REGRESSION TO PERCENTILE BASIS  
FOR BODY DIMENSIONS

Program GOOD computes values of body dimensions for a particular subject by using two fixed percentiles. The user selects a percentile for stature, and dimensions 23 through 31 (see Table 1) are computed to be the same percentile. The user also selects a percentile for sitting height, and dimensions 2 through 22 and 32 and 33 are computed to be this percentile. The percentile values are computed by use of a mean value and standard deviation for each body dimension, along with the assumption that each of the body dimension measurements are normally distributed.

The problem with this approach is that when component dimensions are all set to a fixed percentile, the resulting whole is of a different percentile. This can be illustrated by considering three populations A, B, and C. Each of these populations consists of  $n$  measurements, referred to as  $a_i$ ,  $b_i$ ,  $c_i$  ( $i = 1, n$ ), and for each  $i$  ( $i = 1, n$ )  $a_i + b_i = c_i$ . The mean of the A, B, and C populations are  $\bar{a}$ ,  $\bar{b}$ , and  $\bar{c}$ , respectively, and  $s_a$ ,  $s_b$ ,  $s_c$  are the respective standard deviations of the three populations. Assuming a normal distribution for each of the populations, a specific percentile point may be computed as being a certain number of standard deviations away from the mean. Thus if  $a_m$ ,  $b_m$ , and  $c_m$  are the  $m^{\text{th}}$  percentile points of their respective populations, there exists an  $\alpha$  such that  $a_m = \bar{a} + \alpha s_a$ ,  $b_m = \bar{b} + \alpha s_b$ , and  $c_m = \bar{c} + \alpha s_c$ . Ideally  $a_m + b_m = c_m$ , however, in general this is not the case, as is shown in the following:

$$\begin{aligned}
 c_m &= \bar{c} + \alpha s_c \\
 &= \frac{1}{n} \sum c_i + \frac{\alpha}{n-1} \left[ \sum \left( c_i - \frac{\sum c_i}{n} \right)^2 \right] \\
 &= \frac{1}{n} \sum (a_i + b_i) + \frac{\alpha}{n-1} \left[ \sum (a_i + b_i) - \frac{\sum (a_i + b_i)}{n} \right]^2 \\
 &= \bar{a} + \bar{b} + \frac{\alpha}{n-1} [ \sum ((a_i - \bar{a}) + (b_i - \bar{b}))^2 ]
 \end{aligned}$$

$$\begin{aligned}
 &= \bar{a} + \bar{b} + \frac{\alpha}{n-1} [\sum (a_i - \bar{a})^2 + \sum (b_i - \bar{b})^2 + 2\sum (a_i - \bar{a})(b_i - \bar{b})] \\
 &= a + \alpha s_a + \bar{b} + \alpha s_b + \frac{2\alpha}{n-1} [\sum (a_i - \bar{a})(b_i - \bar{b})] \\
 &= a_m + b_m + \frac{2\alpha}{n-1} [\sum (a_i - \bar{a})(b_i - \bar{b})]
 \end{aligned}$$

where the usual definitions of mean and standard deviation ( $a = \frac{1}{n} \sum a_i$ ,  $s_a = \sqrt{\frac{1}{n-1} \sum (a_i - a)^2}$ , etc.) have been used.

The method used by GEBOD, to determine body dimension values corresponding to a particular subject, is to regress each body dimension against age (for children only), height, and/or weight (see Appendix D). Using the A, B, and C populations to illustrate this method also, least squares linear regressions equations would be developed expressing values from the A and B populations as functions of values from the C populations. That is, the coefficients  $p_a$ ,  $q_a$ ,  $p_b$ , and  $q_b$  would be computed such  $a_o = p_a c_o + q_a$  and  $b_o = p_b c_o + q_b$ , where  $a_o$  is the least squares value from the A population corresponding to  $c_o$  (a value from the C population), and  $b_o$  is the least squares value from the B population corresponding to  $c_o$ . Using standard least squares techniques the values of these parameters are computed as follows:

$$\begin{aligned}
 p_a &= \frac{\sum (a_i - \bar{a})(c_i - \bar{c})}{\sum (c_i - \bar{c})^2}, & q_a &= \bar{a} - p_a \bar{c} \\
 p_b &= \frac{\sum (b_i - \bar{b})(c_i - \bar{c})}{\sum (c_i - \bar{c})^2}, & q_b &= \bar{b} - p_b \bar{c}.
 \end{aligned}$$

The additivity that does not occur with the percentile method can be shown to exist for this regression technique. The first step in showing this is to establish the result  $p_a + p_b = 1$ :

$$p_a + p_b = \frac{\sum (a_i - \bar{a})(c_i - \bar{c})}{\sum (c_i - \bar{c})^2} + \frac{\sum (b_i - \bar{b})(c_i - \bar{c})}{\sum (c_i - \bar{c})^2}$$

$$\begin{aligned}
 &= \frac{\sum [(c_i - \bar{c})(a_i - \bar{a}) + (b_i - \bar{b})]]}{\sum (c_i - \bar{c})^2} \\
 &= \frac{\sum [(c_i - \bar{c})(a_i + b_i - (\bar{a} + \bar{b}))]}{\sum (c_i - \bar{c})^2} \\
 &= \frac{\sum [(c_i - \bar{c})^2]}{\sum (c_i - \bar{c})^2} \\
 &= 1 .
 \end{aligned}$$

Using this result it can be shown that values from the A and B populations,  $a_o$ , and  $b_o$ , respectively, both corresponding to the same value of the C population,  $c_o$ , sum to that value of the C population:

$$\begin{aligned}
 a_o + b_o &= p_a c_o + q_a + p_b c_o + q_b \\
 &= c_o(p_a + p_b) + (q_a + q_b) \\
 &= c_o + (\bar{a} - p_a \bar{c} + \bar{b} - p_b \bar{c}) \\
 &= c_o + (\bar{a} + \bar{b}) - \bar{c}(p_a + p_b) \\
 &= c_o + \bar{c} - \bar{c} \\
 &= c_o .
 \end{aligned}$$

It is for this reason of additivity, that a regression approach was felt to be more correct than the percentile approach of program GOOD as a method of determining body dimensions corresponding to a particular subject, and was therefore used in program GEBOD.

APPENDIX D  
BODY DIMENSION REGRESSION EQUATIONS DEVELOPED FOR GEBOD

This appendix contains a complete listing of the regression equations developed for use by GEBOD. For the adult male and female sets heights and weight are used as predicting variables. The child set uses age along with height and weight. At the top of each set of regression equations is listed the range of values, mean, and standard deviation of the predicting variables within that subject type. For each body dimension a separate regression equation is given against each of the predicting variables. The last regression equation given for each body dimension is a step-wise multiple regression against all of the predicting variables. Since this is a step-wise regression, only those predicting variables that would make a significant contribution to the regression appear in the final form of the regression equation. With each regression equation the square of the correlation coefficient ( $R^{**2}$ ) and the number of subjects the regression equation is based on (NSUB) are given.

REGRESSION EQUATIONS FOR ADULT FEMALES

PREDICTING VARIABLES	RANGE:	MEAN:	MEAN:	RANGE:	MEAN:	MEAN:	RANGE:	RANGE:	RANGE:	RANGE:	RANGE:	RANGE:
WEIGHT STANDING HEIGHT	65.00 56.93	200.0 72.03	127.3 63.82	5.0 : 5.0 :	16.59 2.364							
REGRESSION EQUATIONS FOR WEIGHT												
STANDING HEIGHT	= 1.000	*WEIGHT	+ 4547E-12	R**2 =	1.0000	NSUB = 1905						
WEIGHT	= 3.737	*STANDING	- 111.2	R**2 =	.2836	NSUB = 1905						
WEIGHT	= 1.000	*WEIGHT	+ 4547E-12	R**2 =	1.0000	NSUB = 1905						
REGRESSION EQUATIONS FOR STANDING HEIGHT												
STANDING HEIGHT	= .7589E-01*WEIGHT	+ 54.16	R**2 =	.2836	NSUB = 1905							
STANDING HEIGHT	= 1.000	*STANDING	+ 2274E-12	R**2 =	1.0000	NSUB = 1905						
STANDING HEIGHT	= 1.000	*STANDING	+ 2274E-12	R**2 =	1.0000	NSUB = 1905						
REGRESSION EQUATIONS FOR SHOULDER HEIGHT												
SHOULDER HEIGHT	= .7102E-01*WEIGHT	+ 42.77	R**2 =	.3049	NSUB = 1905							
SHOULDER HEIGHT	= .6751	*STANDING	- 3.936	R**2 =	.9194	NSUB = 1905						
SHOULDER HEIGHT	= .7355E-02*WEIGHT	+ 8469	*STANDING - 3.096	R**2 =	.9210	NSUB = 1905						
REGRESSION EQUATIONS FOR ARMPIT HEIGHT												
ARMPIT HEIGHT	= .5840E-01*WEIGHT	+ 39.83	R**2 =	.2217	NSUB = 1905							
ARMPIT HEIGHT	= .9309	*STANDING	- 5.762	R**2 =	.9115	NSUB = 1905						
ARMPIT HEIGHT	= -.6495E-02*WEIGHT	+ 8551	*STANDING - 6.484	R**2 =	.9135	NSUB = 1905						
REGRESSION EQUATIONS FOR WAIST HEIGHT												
WAIST HEIGHT	= .5302E-01*WEIGHT	+ 32.73	R**2 =	.2465	NSUB = 1905							
WAIST HEIGHT	= .6845	*STANDING	- 4.206	R**2 =	.8346	NSUB = 1905						
WAIST HEIGHT	= .6845	*STANDING	- 4.206	R**2 =	.8346	NSUB = 1905						
REGRESSION EQUATIONS FOR SEATED HEIGHT												
SEATED HEIGHT	= .3620E-01*WEIGHT	+ 29.09	R**2 =	.2317	NSUB = 1905							
SEATED HEIGHT	= .4225	*STANDING	+ 6.734	R**2 =	.6409	NSUB = 1905						
SEATED HEIGHT	= .5777E-02*WEIGHT	+ 4010	*STANDING + 7.376	R**2 =	.6451	NSUB = 1905						
REGRESSION EQUATIONS FOR HEAD LENGTH												
HEAD LENGTH	= .4897E-02*WEIGHT	+ 6.625	R**2 =	.0923	NSUB = 1905							
HEAD LENGTH	= .3600E-01*STANDING	+ 4.950	R**2 =	.1014	NSUB = 1905							
HEAD LENGTH	= .3521E-02*WEIGHT	+ .2471E-01*STANDING	+ 5.286	R**2 =	.1265	NSUB = 1905						
REGRESSION EQUATIONS FOR HEAD BREADTH												
HEAD BREADTH	= .4089E-02*WEIGHT	+ 5.194	R**2 =	.0839	NSUB = 1905							
HEAD BREADTH	= .1347E-01*STANDING	+ 4.855	R**2 =	.0185	NSUB = 1905							
HEAD BREADTH	= .4089E-02*WEIGHT	+ 5.194	R**2 =	.0839	NSUB = 1905							

REGRESSION EQUATIONS FOR HEAD TO CHIN HEIGHT  
 HEAD TO CHIN HEIGHT = .7362E-02\*WEIGHT +7.688  
 HEAD TO CHIN HEIGHT = .6816E-01\*STANDING +4.273  
 HEAD TO CHIN HEIGHT = .3035E-02\*WEIGHT +.5674E-01\*STANDING +4.615

REGRESSION EQUATIONS FOR NECK CIRCUMFERENCE  
 NECK CIRCUMFERENCE = .2316E-01\*WEIGHT +10.34  
 NECK CIRCUMFERENCE = .8900E-01\*STANDING +7.607  
 NECK CIRCUMFERENCE = .2316E-01\*WEIGHT +10.34

REGRESSION EQUATIONS FOR SHOULDER BREADTH  
 SHOULDER BREADTH = .1927E-01\*WEIGHT +11.66  
 SHOULDER BREADTH = .1246 \*STANDING +6.160  
 SHOULDER BREADTH = .1369E-01\*WEIGHT +.7344E-01\*STANDING +7.692

REGRESSION EQUATIONS FOR CHEST DEPTH  
 CHEST DEPTH = .3412E-01\*WEIGHT +4.963  
 CHEST DEPTH = .7300E-01\*STANDING +4.650  
 CHEST DEPTH = .3989E-01\*WEIGHT -.7607E-01\*STANDING +9.086

REGRESSION EQUATIONS FOR CHEST BREADTH  
 CHEST BREADTH = .3105E-01\*WEIGHT +6.969  
 CHEST BREADTH = .8875E-01\*STANDING +5.357  
 CHEST BREADTH = .3505E-01\*WEIGHT -.4222E-01\*STANDING +9.255

REGRESSION EQUATIONS FOR WAIST DEPTH  
 WAIST DEPTH = .3522E-01\*WEIGHT +2.979  
 WAIST DEPTH = .5358E-01\*STANDING +3.279  
 WAIST DEPTH = .3511E-01\*WEIGHT -.7761E-01\*STANDING +7.163

REGRESSION EQUATIONS FOR WAIST BREADTH  
 WAIST BREADTH = .3419E-01\*WEIGHT +5.010  
 WAIST BREADTH = .1060 \*STANDING +2.734  
 WAIST BREADTH = .3800E-01\*WEIGHT -.3598E-01\*STANDING +6.959

REGRESSION EQUATIONS FOR BUTTOCK DEPTH  
 BUTTOCK DEPTH = .3419E-01\*WEIGHT +3.976  
 BUTTOCK DEPTH = .7090E-01\*STANDING +3.803  
 BUTTOCK DEPTH = .4021E-01\*WEIGHT -.7937E-01\*STANDING +6.275

REGRESSION EQUATIONS FOR HIP BREADTH STANDING  
 HIP BREADTH STANDI = .4051E-01\*WEIGHT +8.610  
 HIP BREADTH STANDI = .1295 \*STANDING +5.563  
 HIP BREADTH STANDI = .4294E-01\*WEIGHT -.3192E-01\*STANDING +10.34

R<sup>2</sup> = .0741  
 R<sup>2</sup> = .1290  
 R<sup>2</sup> = .1382

R<sup>2</sup> = .3387  
 R<sup>2</sup> = .1016  
 R<sup>2</sup> = .3387

R<sup>2</sup> = .2451  
 R<sup>2</sup> = .2062  
 R<sup>2</sup> = .2969

R<sup>2</sup> = .5535  
 R<sup>2</sup> = .0515  
 R<sup>2</sup> = .5936

R<sup>2</sup> = .4912  
 R<sup>2</sup> = .0775  
 R<sup>2</sup> = .5037

R<sup>2</sup> = .5422  
 R<sup>2</sup> = .0370  
 R<sup>2</sup> = .5979

R<sup>2</sup> = .5892  
 R<sup>2</sup> = .1081  
 R<sup>2</sup> = .5981

R<sup>2</sup> = .6477  
 R<sup>2</sup> = .0566  
 R<sup>2</sup> = .6985

R<sup>2</sup> = .5935  
 R<sup>2</sup> = .1213  
 R<sup>2</sup> = .5980

REGRESSION EQUATIONS FOR SHOULDER TO ELBOW LENGTH  
 SHOULDER TO ELBOW : .1702E-01\*WEIGHT +10.04  
 SHOULDER TO ELBOM : .1962 \*STANDING -.3163  
 SHOULDER TO ELBOM : .2976E-02\*WEIGHT +.1051 \*STANDING +.1459E-01

R<sup>2</sup>=.992 : .1946 NSUB = 1905  
 P=.992 : .5252 NSUB = 1905  
 R=.992 : .5295 NSUB = 1905

REGRESSION EQUATIONS FOR FOREARM-HAND LENGTH  
 FOREARM-HAND LENGTH : .2092E-01\*WEIGHT +13.78  
 FOREARM-HAND LENGTH : .2478 \*STANDING +6.6324  
 FOREARM-HAND LENGTH : .2960E-02\*WEIGHT +.2367 \*STANDING +.9619

R<sup>2</sup>=.992 : .1941 NSUB = 1905  
 P=.992 : .5526 NSUB = 1905  
 R=.992 : .5554 NSUB = 1905

REGRESSION EQUATIONS FOR BICEPS CIRCUMFERENCE  
 BICEPS CIRCUMFERENC : .4369E-01\*WEIGHT +4.522  
 BICEPS CIRCUMFERENC : .5386E-01\*WEIGHT +6.646  
 BICEPS CIRCUMFERENC : .5528E-01\*WEIGHT -.1527 \*STANDING +12.79

R<sup>2</sup>=.992 : .6442 NSUB = 1905  
 P=.992 : .0199 NSUB = 1905  
 R=.992 : .7587 NSUB = 1905

REGRESSION EQUATIONS FOR FOREARM CIRCUMFERENCE  
 ELBOW CIRCUMFERENC : .2421E-01\*WEIGHT +7.539  
 ELBOW CIRCUMFERENC : .1221 \*STANDING +2.926  
 ELBOW CIRCUMFERENC : .2085E-01\*WEIGHT +.4420E-01\*STANDING +5.145

R<sup>2</sup>=.992 : .3274 NSUB = 1905  
 P=.992 : .1692 NSUB = 1905  
 R=.992 : .3433 NSUB = 1905

REGRESSION EQUATIONS FOR ELBOW CIRCUMFERENCE  
 FOREARM CIRCUMFERENC : .2643E-01\*WEIGHT +5.879  
 FOREARM CIRCUMFERENC : .7088E-01\*WEIGHT +4.719  
 FOREARM CIRCUMFERENC : .2938E-01\*WEIGHT -.3890E-01\*STANDING +7.986

R<sup>2</sup>=.992 : .6524 NSUB = 1905  
 P=.992 : .0953 NSUB = 1905  
 R=.992 : .6730 NSUB = 1905

REGRESSION EQUATIONS FOR WRIST CIRCUMFERENCE  
 WRIST CIRCUMFERENC : .1090E-01\*WEIGHT +4.503  
 WRIST CIRCUMFERENC : .5371E-01\*STANDING +2.463  
 WRIST CIRCUMFERENC : .9530E-02\*WEIGHT +.1810E-01\*STANDING +3.523

R<sup>2</sup>=.992 : .4168 NSUB = 1905  
 P=.992 : .2054 NSUB = 1905  
 R=.992 : .4335 NSUB = 1905

REGRESSION EQUATIONS FOR KNEE HEIGHT, SEATED  
 KNEE HEIGHT, SEATED : .3002E-01\*WEIGHT +14.98  
 KNEE HEIGHT, SEATED : .3345 \*STANDING +2.547  
 KNEE HEIGHT, SEATED : .6469E-02\*WEIGHT +.3104 \*STANDING -1.828

R<sup>2</sup>=.992 : .2549 NSUB = 1905  
 P=.992 : .6428 NSUB = 1905  
 R=.992 : .6512 NSUB = 1905

REGRESSION EQUATIONS FOR THIGH CIRCUMFERENCE  
 THIGH CIRCUMFERENC : .8417E-01\*WEIGHT +11.13  
 THIGH CIRCUMFERENC : .1869 \*STANDING +9.912  
 THIGH CIRCUMFERENC : .9769E-01\*WEIGHT -.1781 \*STANDING +20.77

R<sup>2</sup>=.992 : .7063 NSUB = 1905  
 P=.992 : .0707 NSUB = 1905  
 R=.992 : .7523 NSUB = 1905

REGRESSION EQUATIONS FOR UPPER LEG CIRCUMFERENCE  
 UPPER LEG CIRCUMFE : .6412E-01\*WEIGHT +9.905  
 UPPER LEG CIRCUMFE : .1664 \*STANDING +7.448  
 UPPER LEG CIRCUMFE : .7187E-01\*WEIGHT -.1022 \*STANDING +15.44

R<sup>2</sup>=.992 : .7710 NSUB = 1905  
 P=.992 : .1054 NSUB = 1905  
 R=.992 : .7995 NSUB = 1905

## REGRESSION EQUATIONS FOR KNEE CIRCUMFERENCE

KNEE CIRCUMFERENCE = .4405E-01\*MEIGHT +8.684  
 KNEE CIRCUMFERENCE = .1458 \*STANDING +4.985  
 KNEE CIRCUMFERENCE = .4603E-01\*MEIGHT -.2626E-01\*STANDING -10.11

## REGRESSION EQUATIONS FOR CALF CIRCUMFERENCE

CALF CIRCUMFERENCE = .4012E-01\*MEIGHT +8.393  
 CALF CIRCUMFERENCE = .1106 \*STANDING +6.398  
 CALF CIRCUMFERENCE = .4429E-01\*MEIGHT -.3493E-01\*STANDING +11.31

## REGRESSION EQUATIONS FOR ANKLE CIRCUMFERENCE

ANKLE CIRCUMFERENCE = .1807E-01\*MEIGHT +5.999  
 ANKLE CIRCUMFERENCE = .7603E-01\*STANDING +3.449  
 ANKLE CIRCUMFERENCE = .1720E-01\*MEIGHT +.1177E-01\*STANDING +5.361

## REGRESSION EQUATIONS FOR ANKLE HEIGHT, OUTSIDE

ANKLE HEIGHT, OUTSI = .3434E-02\*MEIGHT +2.230  
 ANKLE HEIGHT, OUTSI = .4163E-01\*STANDING +.9788E-02  
 ANKLE HEIGHT, OUTSI = .4163E-01\*STANDING +.9788E-02

## REGRESSION EQUATIONS FOR FOOT BREADTH

FOOT BREADTH = .4638E-02\*MEIGHT +2.901  
 FOOT BREADTH = .2947E-01\*STANDING +1.611  
 FOOT BREADTH = .3353E-02\*MEIGHT +.1694E-01\*STANDING +1.984

## REGRESSION EQUATIONS FOR FOOT LENGTH

FOOT LENGTH = .1365E-01\*MEIGHT +7.738  
 FOOT LENGTH = .1299 \*STANDING +1.186  
 FOOT LENGTH = .5296E-02\*MEIGHT +.1101 \*STANDING +1.775

R\*\*2 = .6714  
 R\*\*2 = .1494  
 R\*\*2 = .6749

R\*\*2 = .3661  
 R\*\*2 = .0873  
 R\*\*2 = .3616

R\*\*2 = .3496  
 R\*\*2 = .1254  
 R\*\*2 = .3517

R\*\*2 = .0607  
 R\*\*2 = .1813  
 R\*\*2 = .1613

R\*\*2 = .1541  
 R\*\*2 = .1263  
 R\*\*2 = .1640

R\*\*2 = .2601  
 R\*\*2 = .4763  
 R\*\*2 = .5063

## REGRESSION EQUATIONS FOR ADULT MALES

PREDICTING VARIABLES	RANGE:	MEAN:	S.D.:	R <sup>2</sup> :	R <sup>2</sup> :	R <sup>2</sup> :	R <sup>2</sup> :
WEIGHT STANDING HEIGHT	RANGE: 110.0 RANGE: 62.17	MEAN: 764.0 MEAN: 77.64	S.D.: 69.82	R <sup>2</sup> : .9095E-12			
REGRESSION EQUATIONS FOR WEIGHT				R <sup>2</sup> : 1.0000			
WEIGHT WEIGHT WEIGHT WEIGHT	= 1.0000 = 4.530 = 1.0000 = 1.0000	*WEIGHT *STANDING *WEIGHT *WEIGHT	+ .9095E-12 -142.7 + .9095E-12 + .9095E-12	R <sup>2</sup> : .2650			
REGRESSION EQUATIONS FOR STANDING HEIGHT				R <sup>2</sup> : .2650			
STANDING HEIGHT STANDING HEIGHT STANDING HEIGHT	= 1.0000 = 1.0000 = 1.0000	*STANDING *STANDING *STANDING	+ .4547E-12 + .4547E-12 + .4547E-12	R <sup>2</sup> : 1.0000			
REGRESSION EQUATIONS FOR SHOULDER HEIGHT				R <sup>2</sup> : .3058			
SHOULDER HEIGHT SHOULDER HEIGHT SHOULDER HEIGHT	= .5844E-01*WEIGHT = .6911 *STANDING = .6583E-02*WEIGHT	+ .47.02 -5.049 + .6522	+ .59.66 + .4547E-12 + .4547E-12	R <sup>2</sup> : .9163			
REGRESSION EQUATIONS FOR ARMPIT HEIGHT				R <sup>2</sup> : .9231			
ARMPIT HEIGHT ARMPIT HEIGHT ARMPIT HEIGHT	= .4637E-01*WEIGHT = .8398 *STANDING = -.3761E-02*WEIGHT	+ .43.06 -7.529 + .8569	+ .824 + .824 + .824	R <sup>2</sup> : .9011			
REGRESSION EQUATIONS FOR WAIST HEIGHT				R <sup>2</sup> : .2125			
WAIST HEIGHT WAIST HEIGHT WAIST HEIGHT	= .3642E-01*WEIGHT = .7043 *STANDING = -.6506E-02*WEIGHT	+ .35.59 -7.256 + .7338	+ .066 + .066 + .066	R <sup>2</sup> : .9001			
REGRESSION EQUATIONS FOR SEALED HEIGHT				R <sup>2</sup> : .1764			
SEALED HEIGHT SEALED HEIGHT SEALED HEIGHT	= .2664E-01*WEIGHT = .4043 *STANDING = .4060E-02*WEIGHT	+ .32.06 + .8.460 + .3859	+ .039 + .039 + .039	R <sup>2</sup> : .8519			
REGRESSION EQUATIONS FOR HEAD LENGTH				R <sup>2</sup> : .8560			
HEAD LENGTH HEAD LENGTH HEAD LENGTH	= .3209E-02*WEIGHT = .2680E-01*STANDING = .2233E-02*WEIGHT	+ .7.266 + .5.952 + .1668E-01*STANDING	+ .271 + .271 + .271	R <sup>2</sup> : .6241			
REGRESSION EQUATIONS FOR HEAD BREADTH				R <sup>2</sup> : .2086			
HEAD BREADTH HEAD BREADTH HEAD BREADTH	= .3060E-02*WEIGHT = .1174E-01*STANDING = .3060E-02*WEIGHT	+ 5.611 + 5.322 + 5.611	+ .271 + .271 + .271	R <sup>2</sup> : .6205			
REGRESSION EQUATIONS FOR HEAD BREADTH				R <sup>2</sup> : .0846			
HEAD BREADTH HEAD BREADTH HEAD BREADTH	= .0943 = .0179 = .0943	- .0943 - .0179 - .0943	- .271 - .271 - .271	R <sup>2</sup> : .0673			
REGRESSION EQUATIONS FOR HEAD BREADTH				R <sup>2</sup> : .0606			
HEAD BREADTH HEAD BREADTH HEAD BREADTH	= .0943 = .0943 = .0943	- .0943 - .0943 - .0943	- .271 - .271 - .271	R <sup>2</sup> : .0846			

REGRESSION EQUATIONS FOR HEAD TO CHIN HEIGHT  
 HEAD TO CHIN HEIGHT = .3143E-02\*WEIGHT +8.420  
 HEAD TO CHIN HEIGHT = .4632E-01\*STANDING +5.712  
 HEAD TO CHIN HEIGHT = .4632E-01\*STANDING +5.712

R<sup>2</sup> = .0281  
 R<sub>adj</sub><sup>2</sup> = .0796  
 R<sub>adj</sub><sup>2</sup> = .0796  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR NECK CIRCUMFERENCE  
 NECK CIRCUMFERENCE = .2444E-01\*WEIGHT +10.85  
 NECK CIRCUMFERENCE = .5327E-01\*STANDING +10.54  
 NECK CIRCUMFERENCE = .2805E-01\*WEIGHT -.6105E-01\*STANDING +14.54

R<sup>2</sup> = .4865  
 R<sub>adj</sub><sup>2</sup> = .0449  
 R<sub>adj</sub><sup>2</sup> = .5160  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR SHOULDER BREADTH  
 SHOULDER BREADTH = .1612E-01\*WEIGHT +13.24  
 SHOULDER BREADTH = .1181 \*STANDING +7.790  
 SHOULDER BREADTH = .1253E-01\*WEIGHT +.6133E-01\*STANDING +9.579

R<sup>2</sup> = .2043  
 R<sub>adj</sub><sup>2</sup> = .1416  
 R<sub>adj</sub><sup>2</sup> = .2323  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR CHEST DEPTH  
 CHEST DEPTH = .2690E-01\*WEIGHT +4.984  
 CHEST DEPTH = .5114E-01\*STANDING +5.386  
 CHEST DEPTH = .3174E-01\*WEIGHT -.0265E-01\*STANDING +9.915

R<sup>2</sup> = .5767  
 R<sub>adj</sub><sup>2</sup> = .0385  
 R<sub>adj</sub><sup>2</sup> = .6284  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR WAIST DEPTH  
 WAIST DEPTH = .2911E-01\*WEIGHT +7.854  
 WAIST DEPTH = .8877E-01\*STANDING +6.709  
 WAIST DEPTH = .3234E-01\*WEIGHT -.5866E-01\*STANDING +11.35

R<sup>2</sup> = .5608  
 R<sub>adj</sub><sup>2</sup> = .0673  
 R<sub>adj</sub><sup>2</sup> = .5824  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR WAIST BREADTH  
 WAIST BREADTH = .3026E-01\*WEIGHT +3.528  
 WAIST BREADTH = .5167E-01\*STANDING +5.174  
 WAIST BREADTH = .3706E-01\*WEIGHT -.11162 \*STANDING +10.46

R<sup>2</sup> = .5712  
 R<sub>adj</sub><sup>2</sup> = .0215  
 R<sub>adj</sub><sup>2</sup> = .6512  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR BUTTOCK DEPTH  
 BUTTOCK DEPTH = .3741E-01\*WEIGHT +5.694  
 BUTTOCK DEPTH = .1105 \*STANDING +4.473  
 BUTTOCK DEPTH = .4211E-01\*WEIGHT -.8023E-01\*STANDING +10.49

R<sup>2</sup> = .7269  
 R<sub>adj</sub><sup>2</sup> = .0819  
 R<sub>adj</sub><sup>2</sup> = .7586  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR BUTTOCK DEPTH  
 BUTTOCK DEPTH = .3077E-01\*WEIGHT +4.095  
 BUTTOCK DEPTH = .6397E-01\*STANDING +4.566  
 BUTTOCK DEPTH = .3632E-01\*WEIGHT -.9475E-01\*STANDING +9.749

R<sup>2</sup> = .6664  
 R<sub>adj</sub><sup>2</sup> = .0442  
 R<sub>adj</sub><sup>2</sup> = .7263  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR HIP BREADTH, STANDING  
 HIP BREADTH, STANDI = .2803E-01\*WEIGHT +9.019  
 HIP BREADTH, STANDI = .4258 \*STANDING +5.100  
 HIP BREADTH, STANDI = .2803E-01\*WEIGHT +9.019

R<sup>2</sup> = .6556  
 R<sub>adj</sub><sup>2</sup> = .1706  
 R<sub>adj</sub><sup>2</sup> = .6556  
 NSUB = 2420  
 NSUB = 2420  
 NSUB = 2420

REGRESSION EQUATIONS FOR SHOULDER TO ELBOW LENGTH  
 SHOULDER TO ELBOW = .1256E-01\*WEIGHT +11.97  
 SHOULDER TO ELBOW = .2087 \*STANDING -.4158  
 SHOULDER TO ELBOW = .2087 \*STANDING -.4158

REGRESSION EQUATIONS FOR FOREARM-HAND LENGTH  
 FOREARM-HAND LENGTH = .1671E-01\*WEIGHT +16.54  
 FOREARM-HAND LENGTH = .2646 \*STANDING +.9735  
 FOREARM-HAND LENGTH = .1677E-02\*WEIGHT +.2570 \*STANDING +1.213

REGRESSION EQUATIONS FOR BICEPS CIRCUMFERENCE  
 BICEPS CIRCUMFEREN = .3340E-01\*WEIGHT +6.608  
 BICEPS CIRCUMFEREN = .5996E-01\*STANDING +8.219  
 BICEPS CIRCUMFEREN = .4067E-01\*WEIGHT -.1243 \*STANDING +14.02

REGRESSION EQUATIONS FOR ELBOW CIRCUMFERENCE  
 ELBOW CIRCUMFERENC = .1919E-01\*WEIGHT +8.967  
 ELBOW CIRCUMFERENC = .1061 \*STANDING +4.894  
 ELBOW CIRCUMFERENC = .1767E-01\*WEIGHT +.2601E-01\*STANDING +7.416

REGRESSION EQUATIONS FOR FOREARM CIRCUMFERENCE  
 FOREARM CIRCUMFERE = .2116E-01\*WEIGHT +7.411  
 FOREARM CIRCUMFERE = .6768E-01\*STANDING +6.359  
 FOREARM CIRCUMFERE = .2341E-01\*WEIGHT -.3835E-01\*STANDING +9.700

REGRESSION EQUATIONS FOR WRIST CIRCUMFERENCE  
 WRIST CIRCUMFERENC = .9921E-02\*WEIGHT +5.202  
 WRIST CIRCUMFERENC = .5166E-01\*STANDING +3.317  
 WRIST CIRCUMFERENC = .9306E-02\*WEIGHT +.9137E-02\*STANDING +4.657

REGRESSION EQUATIONS FOR KNEE HEIGHT, SEATED  
 KNEE HEIGHT,SEATED = .2467E-01\*WEIGHT +17.67  
 KNEE HEIGHT,SEATED = .3558 \*STANDING +2.889  
 KNEE HEIGHT,SEATED = .5244E-02\*WEIGHT +.3321 \*STANDING -2.141

REGRESSION EQUATIONS FOR THIGH CIRCUMFERENCE  
 THIGH CIRCUMFERENC = .6598E-01\*WEIGHT +11.01  
 THIGH CIRCUMFERENC = .1614 \*STANDING +11.89  
 THIGH CIRCUMFERENC = .0237E-01\*WEIGHT -.2117 \*STANDING +23.64

REGRESSION EQUATIONS FOR UPPER LEG CIRCUMFERENCE  
 UPPER LEG CIRCUMFE = .3229E-01\*WEIGHT +9.621  
 UPPER LEG CIRCUMFE = .1412 \*STANDING +5.370  
 UPPER LEG CIRCUMFE = .3229E-01\*WEIGHT +9.621

Res2 = .1595 NSUB = 2420  
 Res2 = .5683 NSUB = 2420  
 Res2 = .5683 NSUB = 2420

Res2 = .1621 NSUB = 2420  
 Res2 = .5245 NSUB = 2420  
 Res2 = .5256 NSUB = 2420

Res2 = .6711 NSUB = 2420  
 Res2 = .0279 NSUB = 2420  
 Res2 = .7593 NSUB = 2420

Res2 = .3983 NSUB = 2420  
 Res2 = .1413 NSUB = 2420  
 Res2 = .3645 NSUB = 2420

Res2 = .6225 NSUB = 2420  
 Res2 = .0822 NSUB = 2420  
 Res2 = .6419 NSUB = 2420

Res2 = .3446 NSUB = 2420  
 Res2 = .1207 NSUB = 2420  
 Res2 = .3474 NSUB = 2420

Res2 = .2900 NSUB = 2420  
 Res2 = .7709 NSUB = 2420  
 Res2 = .7685 NSUB = 2420

Res2 = .7392 NSUB = 2420  
 Res2 = .0506 NSUB = 2420  
 Res2 = .8034 NSUB = 2420

REGRESSION EQUATIONS FOR KNEE CIRCUMFERENCE

KNEE CIRCUMFERENCE = .3334E-01\*WEIGHT +9.696  
 KNEE CIRCUMFERENCE = .1512 \*STANDING +4.910  
 KNEE CIRCUMFERENCE = .3334E-01\*WEIGHT +9.696

REGRESSION EQUATIONS FOR CALF CIRCUMFERENCE

CALF CIRCUMFERENCE = .3250E-01\*WEIGHT +9.002  
 CALF CIRCUMFERENCE = .8842E-01\*STANDING +6.469  
 CALF CIRCUMFERENCE = .3710E-01\*WEIGHT -.8000E-01\*STANDING +13.77

REGRESSION EQUATIONS FOR ANKLE CIRCUMFERENCE

ANKLE CIRCUMFERENCE = .1610E-01\*WEIGHT +6.028  
 ANKLE CIRCUMFERENCE = .6599E-01\*STANDING +4.216  
 ANKLE CIRCUMFERENCE = .1665E-01\*WEIGHT -.9456E-02\*STANDING +6.593

REGRESSION EQUATIONS FOR ANKLE HEIGHT, OUTSIDE

ANKLE HEIGHT,OUTSI = .4310E-02\*WEIGHT +4.652  
 ANKLE HEIGHT,OUTSI = .8736E-01\*STANDING -.6990  
 ANKLE HEIGHT,OUTSI = -.1090E-02\*WEIGHT +.9230E-01\*STANDING -.8343

REGRESSION EQUATIONS FOR FOOT BREADTH

FOOT BREADTH = .4136E-02\*WEIGHT +3.127  
 FOOT BREADTH = .341BE-01\*STANDING +1.459  
 FOOT BREADTH = -.2907E-02\*WEIGHT +.2101E-01\*STANDING +1.673

REGRESSION EQUATIONS FOR FOOT LENGTH

FOOT LENGTH = .1028E-01\*WEIGHT +8.058  
 FOOT LENGTH = .11309 \*STANDING +1.502  
 FOOT LENGTH = .3570E-02\*WEIGHT +.1146 \*STANDING +2.012

R <sub>002</sub> =	.7310	NSUB = 2420
R <sub>002</sub> =	.1941	NSUB = 2420
R <sub>002</sub> =	.7310	NSUB = 2420
R <sub>002</sub> =	.6081	NSUB = 2420
R <sub>002</sub> =	.0581	NSUB = 2420
R <sub>002</sub> =	.6430	NSUB = 2420
R <sub>002</sub> =	.4917	NSUB = 2420
R <sub>002</sub> =	.1045	NSUB = 2420
R <sub>002</sub> =	.4832	NSUB = 2420
R <sub>002</sub> =	.0419	NSUB = 2420
R <sub>002</sub> =	.2223	NSUB = 2420
R <sub>002</sub> =	.2242	NSUB = 2420
R <sub>002</sub> =	.2068	NSUB = 2420
R <sub>002</sub> =	.1824	NSUB = 2420
R <sub>002</sub> =	.2575	NSUB = 2420
R <sub>002</sub> =	.2214	NSUB = 2420
R <sub>002</sub> =	.4634	NSUB = 2420
R <sub>002</sub> =	.4830	NSUB = 2420

## REGRESSION EQUATIONS FOR CHILDREN

PREDICTING VARIABLES	RANGE:	MEAN:	S. D.:
AGE	24.00	240.0	53.02
WEIGHT	22.27	247.6	39.18
STANDING HEIGHT	32.01	76.54	9.741
REgression Equations for AGE			
AGE	= 1.000	*AGE	.4547E-12
WEIGHT	= 1.213	*WEIGHT	.25.43
AGE	= 5.202	*STANDING	-158.9
AGE	= 1.000	*AGE	.4547E-12
REgression Equations for WEIGHT			
WEIGHT	= .6625	*AGE	.7660
WEIGHT	= 1.000	*WEIGHT	.4547E-12
WEIGHT	= 3.743	*STANDING	-122.2
WEIGHT	= 1.000	*WEIGHT	.4547E-12
REgression Equations for STANDING HEIGHT			
STANDING HEIGHT	= .1736	*AGE	.32.62
STANDING HEIGHT	= .2314	*WEIGHT	.35.59
STANDING HEIGHT	= 1.000	*STANDING	.2274E-12
STANDING HEIGHT	= 1.000	*STANDING	.2274E-12
REgression Equations for SHOULDER HEIGHT			
SHOULDER HEIGHT	= .1516	*AGE	.24.79
SHOULDER HEIGHT	= .1994	*WEIGHT	.27.37
SHOULDER HEIGHT	= .6721	*STANDING	-3.898
SHOULDER HEIGHT	= .6721	*STANDING	-3.898
REgression Equations for ARMPIT HEIGHT			
ARMPIT HEIGHT	= .1467	*AGE	.22.53
ARMPIT HEIGHT	= .1916	*WEIGHT	.25.19
ARMPIT HEIGHT	= .9315	*STANDING	-4.469
ARMPIT HEIGHT	= -.1217E-01*WEIGHT	*STANDING	-5.954
REgression Equations for WAIST HEIGHT			
WAIST HEIGHT	= .1196	*AGE	.19.17
WAIST HEIGHT	= .1530	*WEIGHT	.19.97
WAIST HEIGHT	= .6822	*STANDING	-4.726
WAIST HEIGHT	= -.1855E-01*WEIGHT	*STANDING	-7.012
REgression Equations for SEATED HEIGHT			
SEATED HEIGHT	= .7804E-01*AGE	*WEIGHT	.8929
SEATED HEIGHT	= .1047	*WEIGHT	.8475
SEATED HEIGHT	= .4412	*STANDING	.9921
SEATED HEIGHT	= .5848E-02*AGE	*WEIGHT	.9926
REgression Equations for HEAD LENGTH			
HEAD LENGTH	= .3642E-02*AGE	+6.881	.8944
HEAD LENGTH	= .5571E-02*WEIGHT	+6.881	.8785
HEAD LENGTH	= .2249E-01*STANDING	+6.110	.9641
HEAD LENGTH	= -.3975E-02*AGE	*WEIGHT	.9686

## REGRESSION EQUATIONS FOR HEAD BREADTH

HEAD BREADTH	= .3642E-02*AGE	+5.220		
HEAD BREADTH	= .53337E-02*WEIGHT	+5.237		
HEAD BREADTH	= .2036E-01*STANDING	+4.532		
HEAD BREADTH	= -.6471E-03*AGE	.+3641E-02*WEIGHT	.+1071E-01*STANDING	+4.873

## REGRESSION EQUATIONS FOR HEAD TO CHIN HEIGHT

HEAD TO CHIN HEIGHT	= .8988E-02*AGE	+6.582		
HEAD TO CHIN HEIGHT	= .1266E-01*WEIGHT	+6.666		
HEAD TO CHIN HEIGHT	= .5203E-01*STANDING	+4.967		
HEAD TO CHIN HEIGHT	= -.2157E-02*AGE	.+4550E-02*WEIGHT	.+4621E-01*STANDING	+5.080

## REGRESSION EQUATIONS FOR NECK CIRCUMFERENCE

NECK CIRCUMFERENCE	= .2281E-01*AGE	+8.421		
NECK CIRCUMFERENCE	= .3449E-01*WEIGHT	+8.448		
NECK CIRCUMFERENCE	= .1301 STANDING	+4.177		
NECK CIRCUMFERENCE	= -.2812E-02*AGE	.+3292E-01*WEIGHT	.+2141E-01*STANDING	+7.760

## REGRESSION EQUATIONS FOR SHOULDER BREADTH

SHOULDER BREADTH	= .3595E-01*AGE	+7.530		
SHOULDER BREADTH	= .4866E-01*WEIGHT	+8.020		
SHOULDER BREADTH	= .2040 STANDING	+6.9749		
SHOULDER BREADTH	= .4037E-02*AGE	.+1483E-01*WEIGHT	.+1271 STANDING	+3.354

## REGRESSION EQUATIONS FOR CHEST DEPTH

CHEST DEPTH	= .2870E-01*AGE	+5.225		
CHEST DEPTH	= .4229E-01*WEIGHT	+5.333		
CHEST DEPTH	= .1620 STANDING	-2.418E-01		
CHEST DEPTH	= .3765E-01*WEIGHT	.+2091E-01*STANDING	.+4.589	

## REGRESSION EQUATIONS FOR WAIST DEPTH

WAIST DEPTH	= .2699E-01*AGE	+5.195		
WAIST DEPTH	= .3895E-01*WEIGHT	+5.411		
WAIST DEPTH	= .1504 STANDING	.+3666		
WAIST DEPTH	= .4513E-02*AGE	.+2798E-01*WEIGHT	.+2213E-01*STANDING	+4.506

## REGRESSION EQUATIONS FOR WAIST BREADTH

WAIST BREADTH	= .1284E-01*AGE	+5.024		
WAIST BREADTH	= .2279E-01*WEIGHT	+4.763		
WAIST BREADTH	= .7598E-01*STANDING	+2.485		
WAIST BREADTH	= .9176E-02*AGE	.+3995E-01*WEIGHT	-.3147E-01*STANDING	+6.097

## REGRESSION EQUATIONS FOR BUTTOCK DEPTH

BUTTOCK DEPTH	= .2710E-01*AGE	+5.367		
BUTTOCK DEPTH	= .3977E-01*WEIGHT	+5.508		
BUTTOCK DEPTH	= .1522 STANDING	.+4650		
BUTTOCK DEPTH	= .3925E-02*AGE	.+3503E-01*WEIGHT	.+5.406	

Res2 = .4591	NSUB = 3782		
Res2 = .5367	NSUB = 3782		
Res2 = .5129	NSUB = 3782		
Res2 = .5468	NSUB = 3782		
Res2 = .5869	NSUB = 1262		
Res2 = .6370	NSUB = 1262		
Res2 = .6674	NSUB = 1262		
Res2 = .6806	NSUB = 1262		
Res2 = .7077	NSUB = 1310		
Res2 = .8670	NSUB = 1310		
Res2 = .7824	NSUB = 1310		
Res2 = .8892	NSUB = 1310		
Res2 = .8727	NSUB = 1239		
Res2 = .8764	NSUB = 1239		
Res2 = .9328	NSUB = 1239		
Res2 = .9460	NSUB = 1239		
Res2 = .7190	NSUB = 1308		
Res2 = .8665	NSUB = 1308		
Res2 = .7786	NSUB = 1308		
Res2 = .8682	NSUB = 1308		
Res2 = .7952	NSUB = 1311		
Res2 = .8917	NSUB = 1311		
Res2 = .9386	NSUB = 1311		
Res2 = .9034	NSUB = 1311		
Res2 = .3173	NSUB = 1301		
Res2 = .5504	NSUB = 1301		
Res2 = .3761	NSUB = 1301		
Res2 = .6063	NSUB = 1301		
Res2 = .7342	NSUB = 1310		
Res2 = .8634	NSUB = 1310		
Res2 = .7820	NSUB = 1310		
Res2 = .8664	NSUB = 1310		
Res2 = .7191	NSUB = 1224		
Res2 = .8631	NSUB = 1224		
Res2 = .7468	NSUB = 1224		
Res2 = .8653	NSUB = 1224		

## REGRESSION EQUATIONS FOR HIP BREADTH, STANDING

HIP BREADTH STANDI = .3552E-01\*AGE +5.542  
 HIP BREADTH STANDI = .4957E-01\*WEIGHT +5.963  
 HIP BREADTH STANDI = .1968 \*STANDING -.7718  
 HIP BREADTH STANDI = .1151E-01\*AGE +.3192E-01\*WEIGHT +.1642E-01\*STANDING +5.020

R<sub>se2</sub> = .8640  
 R<sub>se2</sub> = .9229  
 R<sub>se2</sub> = .8911  
 R<sub>se2</sub> = .9477  
 NSUB = 1234  
 NSUB = 1234  
 NSUB = 1234  
 NSUB = 1234

## REGRESSION EQUATIONS FOR SHOULDER TO ELBOW LENGTH

SHOULDER TO ELBOW = .3933E-01\*AGE +6.369  
 SHOULDER TO ELBOW = .5175E-01\*WEIGHT +7.039  
 SHOULDER TO ELBOW = .2237 \*STANDING -.9239  
 SHOULDER TO ELBOW = .6433E-03\*AGE +.2193 \*STANDING -.7898

R<sub>se2</sub> = .8922  
 R<sub>se2</sub> = .8440  
 R<sub>se2</sub> = .9735  
 R<sub>se2</sub> = .9736  
 NSUB = 3623  
 NSUB = 3623  
 NSUB = 3623  
 NSUB = 3623

## REGRESSION EQUATIONS FOR FOREARM-HAND LENGTH

FOREARM-HAND LENGTH = .4900E-01\*AGE +8.421  
 FOREARM-HAND LENGTH = .6536E-01\*WEIGHT +9.162  
 FOREARM-HAND LENGTH = .2804 \*STANDING -.7587  
 FOREARM-HAND LENGTH = -.2689E-02\*AGE +.4490E-02\*WEIGHT +.2776 \*STANDING -.6374

R<sub>se2</sub> = .8783  
 R<sub>se2</sub> = .8541  
 R<sub>se2</sub> = .9701  
 R<sub>se2</sub> = .9709  
 NSUB = 3621  
 NSUB = 3621  
 NSUB = 3621  
 NSUB = 3621

## REGRESSION EQUATIONS FOR BICEPS CIRCUMFERENCE

BICEPS CIRCUMFEREN = .2664E-01\*AGE +4.976  
 BICEPS CIRCUMFEREN = .4173E-01\*WEIGHT +4.182  
 BICEPS CIRCUMFEREN = .1501 \*STANDING +.1173  
 BICEPS CIRCUMFEREN = .5211E-01\*WEIGHT -.4492E-01\*STANDING +6.476

R<sub>se2</sub> = .6794  
 R<sub>se2</sub> = .9115  
 R<sub>se2</sub> = .7281  
 R<sub>se2</sub> = .9203  
 NSUB = 3624  
 NSUB = 3624  
 NSUB = 3624  
 NSUB = 3624

## REGRESSION EQUATIONS FOR FOREARM CIRCUMFERENCE

ELBOW CIRCUMFEREN = .2267E-01\*AGE +5.152  
 ELBOW CIRCUMFEREN = .3434E-01\*WEIGHT +5.166  
 ELBOW CIRCUMFEREN = .1290 \*STANDING +.9440  
 ELBOW CIRCUMFEREN = -.1938E-02\*AGE +.3358E-01\*WEIGHT +.1344E-01\*STANDING +4.738

R<sub>se2</sub> = .7400  
 R<sub>se2</sub> = .9287  
 R<sub>se2</sub> = .8097  
 R<sub>se2</sub> = .9293  
 NSUB = 3622  
 NSUB = 3622  
 NSUB = 3622  
 NSUB = 3622

## REGRESSION EQUATIONS FOR WRIST CIRCUMFERENCE

WRIST CIRCUMFERE = .2267E-01\*AGE +5.152  
 WRIST CIRCUMFERE = .3434E-01\*WEIGHT +5.166  
 WRIST CIRCUMFERE = .1290 \*STANDING +.9440  
 WRIST CIRCUMFERE = -.1938E-02\*AGE +.3358E-01\*WEIGHT +.1344E-01\*STANDING +4.738

R<sub>se2</sub> = .7400  
 R<sub>se2</sub> = .9287  
 R<sub>se2</sub> = .8097  
 R<sub>se2</sub> = .9293  
 NSUB = 3622  
 NSUB = 3622  
 NSUB = 3622  
 NSUB = 3622

## REGRESSION EQUATIONS FOR KNEE HEIGHT, SEATED

KNEE HEIGHT,SEATED = .1145E-01\*AGE +3.971  
 KNEE HEIGHT,SEATED = .1771E-01\*WEIGHT +3.951  
 KNEE HEIGHT,SEATED = .6620E-01\*STANDING +1.791  
 KNEE HEIGHT,SEATED = -.3479E-02\*AGE +.1804E-01\*WEIGHT +.1674E-01\*STANDING +3.447

R<sub>se2</sub> = .6390  
 R<sub>se2</sub> = .8395  
 R<sub>se2</sub> = .7273  
 R<sub>se2</sub> = .8446  
 NSUB = 1311  
 NSUB = 1311  
 NSUB = 1311  
 NSUB = 1311

## REGRESSION EQUATIONS FOR THIGH CIRCUMFERENCE

THIGH CIRCUMFERENC = .5917E-01\*AGE +9.584  
 THIGH CIRCUMFERENC = .8944E-01\*WEIGHT +10.55  
 THIGH CIRCUMFERENC = .3382 \*STANDING -.1.560  
 THIGH CIRCUMFERENC = .1016E-01\*AGE +.6938E-01\*WEIGHT -.2709E-01\*WEIGHT +10.25

R<sub>se2</sub> = .8612  
 R<sub>se2</sub> = .8222  
 R<sub>se2</sub> = .9693  
 R<sub>se2</sub> = .9714  
 NSUB = 3678  
 NSUB = 3678  
 NSUB = 3678  
 NSUB = 3678

## REGRESSION EQUATIONS FOR UPPER LEG CIRCUMFERENCE

UPPER LEG CIRCUMF = .4805E-01\*AGE +7.998  
 UPPER LEG CIRCUMF = .7076E-01\*WEIGHT +8.195  
 UPPER LEG CIRCUMF = .2691 \*STANDING -.6787  
 UPPER LEG CIRCUMF = .5930E-02\*AGE +8.043

## REGRESSION EQUATIONS FOR KNEE CIRCUMFERENCE

KNEE CIRCUMF = .4805E-01\*AGE +7.998  
 KNEE CIRCUMF = .7076E-01\*WEIGHT +8.195  
 KNEE CIRCUMF = .2691 \*STANDING -.6787  
 KNEE CIRCUMF = .5930E-02\*AGE +8.043

## REGRESSION EQUATIONS FOR CALF CIRCUMFERENCE

CALF CIRCUMF = .3544E-01\*AGE +6.685  
 CALF CIRCUMF = .5209E-01\*WEIGHT +6.839  
 CALF CIRCUMF = .1998 \*STANDING +2129  
 CALF CIRCUMF = .1539E-02\*AGE +.4370E-01\*WEIGHT +.2825E-01\*STANDING +5.794

## REGRESSION EQUATIONS FOR ANKLE CIRCUMFERENCE

ANKLE CIRCUMF = .1270E-01\*AGE +5.116  
 ANKLE CIRCUMF = .2659E-01\*WEIGHT +5.152  
 ANKLE CIRCUMF = .1016 \*STANDING +1.786  
 ANKLE CIRCUMF = -.3664E-02\*AGE +.2284E-01\*WEIGHT +.3523E-01\*STANDING +3.995

## REGRESSION EQUATIONS FOR ANKLE HEIGHT, OUTSIDE

ANKLE HEIGHT,OUTSI = .6637E-02\*AGE +1.319  
 ANKLE HEIGHT,OUTSI = .9232E-02\*WEIGHT +1.417  
 ANKLE HEIGHT,OUTSI = .4015E-01\*STANDING -.2032E-01  
 ANKLE HEIGHT,OUTSI = -.1302E-02\*AGE +.4697E-01\*WEIGHT +.4407E-01\*STANDING +.7576

## REGRESSION EQUATIONS FOR FOOT BREADTH

FOOT BREADTH = .8742E-02\*AGE +2.193  
 FOOT BREADTH = .1221E-01\*WEIGHT +2.283  
 FOOT BREADTH = .5052E-01\*STANDING +.5281  
 FOOT BREADTH = -.1722E-02\*AGE +.4119E-02\*WEIGHT +.4407E-01\*STANDING +.7576

## REGRESSION EQUATIONS FOR FOOT LENGTH

FOOT LENGTH = .2436E-01\*AGE +5.384  
 FOOT LENGTH = .3275E-01\*WEIGHT +5.742  
 FOOT LENGTH = .1416 \*STANDING +.7017  
 FOOT LENGTH = -.5757E-02\*AGE +.1715 \*STANDING - .2125

R\*\*2 = .7829  
 R\*\*2 = .9292  
 R\*\*2 = .8261  
 R\*\*2 = .9316

R\*\*2 = .7829  
 R\*\*2 = .9292  
 R\*\*2 = .8261  
 R\*\*2 = .9316

R\*\*2 = .7907  
 R\*\*2 = .9342  
 R\*\*2 = .8496  
 R\*\*2 = .9380

R\*\*2 = .7020  
 R\*\*2 = .8686  
 R\*\*2 = .7897  
 R\*\*2 = .8741

R\*\*2 = .5237  
 R\*\*2 = .5227  
 R\*\*2 = .5974  
 R\*\*2 = .5992

R\*\*2 = .7591  
 R\*\*2 = .8088  
 R\*\*2 = .8544  
 R\*\*2 = .8687

R\*\*2 = .6191  
 R\*\*2 = .8079  
 R\*\*2 = .9341  
 R\*\*2 = .9380

APPENDIX E  
INERTIAL PROPERTIES OF ELLIPSOIDS AND  
RIGHT ELLIPTICAL CYLINDER STACKS

An ellipsoid with a semiaxis length in the x direction of  $a$ , in the y direction of  $b$ , and in the z direction of  $c$  has volume  $4/3 \pi abc$ . If this ellipsoid is homogeneous with density  $\rho$  its inertial properties are as follows:

$$\begin{aligned}\text{mass} &= 4/3 \pi \rho abc, \\ x \text{ moment of inertia} &= \frac{\text{mass}}{5} (b^2 + c^2), \\ y \text{ moment of inertia} &= \frac{\text{mass}}{5} (a^2 + c^2), \\ z \text{ moment of inertia} &= \frac{\text{mass}}{5} (a^2 + b^2),\end{aligned}$$

and the center of gravity is located at the center of the ellipsoid.

The other geometric model utilized by GEBO for the determination of inertial properties is a stack of right elliptical cylinders.

The cylinders in the stack are numbered from 1 to  $n$  (where there are  $n$  cylinders in the stack) sequentially from one end of the stack to the other. In order to locate the center of gravity of this figure an axis system must be defined. The origin of this axis system is located at the center of the elliptical end surface of cylinder 1 most distant from the center of the stack. The  $x$ ,  $y$ , and  $z$  axes are parallel to the directions of the local reference system of the segment being modeled (see Section 3). The end of the stack is chosen for the origin (and to begin numbering with) so that the positive  $z$  axis passes through all the cylinders.

The cylinders are stacked so that the positive  $z$  axis passes through the center of both elliptical end surfaces of each cylinder. The cylinders are oriented so that one semiaxis (referred to as the  $x$  semiaxis) is parallel to the  $x$  axis, and the other (referred to as the  $y$  semiaxis) is parallel to the  $y$  axis. The length of the  $x$  semiaxis of cylinder  $i$  is referred to as  $a_i$ , and the length of the  $y$

semiaxis is referred to as  $b_i$ . Each cylinder has the same height, called  $h$ . By assumption, each cylinder is also homogeneous with density  $\rho$ , giving the  $i^{\text{th}}$  cylinder the following geometric and inertial properties:

$$\begin{aligned}
 \text{volume} &= v_i = \pi a_i b_i h, \\
 \text{mass} &= m_i = \rho v_i, \\
 \text{x moment of inertia} &= I_{xx_i} = \frac{m_i}{12} (3b_i^2 + h^2), \\
 \text{y moment of inertia} &= I_{yy_i} = \frac{m_i}{12} (3a_i^2 + h^2) \\
 \text{z moment of inertia} &= I_{zz_i} = \frac{m_i}{4} (a_i^2 + b_i^2), \\
 \text{x center of mass coordinate} &= cgx_i = 0.0 \\
 \text{y center of mass coordinate} &= cgy_i = 0.0 \\
 \text{z center of mass coordinate} &= cgz_i = (i - \frac{1}{2})h,
 \end{aligned}$$

where the  $x$ ,  $y$ , and  $z$  moments of inertia are about axes parallel to the  $x$ ,  $y$ , and  $z$  reference axes, respectively, but through the center (both geometric center and center of gravity) of the cylinder.

To compute the mass or volume of the entire stack the individual masses or volumes are summed. The center of mass of the stack is located as follows:

$$\begin{aligned}
 \text{x center of mass coordinate} &= cgx = \frac{\sum m_i c g x_i}{\sum m_i} = 0.0, \\
 \text{y center of mass coordinate} &= cgy = \frac{\sum m_i c g y_i}{\sum m_i} = 0.0, \\
 \text{z center of mass coordinate} &= cgz = \frac{\sum m_i c g z_i}{\sum m_i}.
 \end{aligned}$$

Moments of inertia may be combined by simple summing, as long as they have all been computed relative to the same set of axes. Since different  $x$  and  $y$  axes have been used in the computation of each cylinder's moments of inertia, a single set of axes must be defined, the individual moments of inertia recomputed relative to that set of axes, and then summed. It is standard to express moments of inertia relative to axes at the center of gravity of a body, and

this is assumed by the ATB Model. For this reason a new axis system is defined at the center of mass of the stack and parallel to the old reference system. Since the x and y coordinates of the center of mass, relative to the old system, are both zero, the new and old systems share a common z axis, which is also the z axis relative to which the  $I_{zz_i}$  ( $i = 1, n$ ) were computed. Thus, the moment of inertia of the stack relative to this new z axis is simply the sum of the individual  $I_{zz_i}$ . Since the x axes relative to which the  $I_{xx_i}$  ( $i = 1, n$ ) were computed are all parallel to the x axis of the new system, the parallel axis theorem may be used to recompute the moments of inertia of each cylinder relative to the new system's x axis, and these values may then be summed. The same procedure is then applied to the moments of inertia about y. These computations which determine the moments of inertia of the entire stack are summarized as follows:

$$x \text{ moment of inertia} = I_{xx} = \sum_{i=1}^n [I_{xx_i} + m_i (cgz - cgz_i)^2],$$

$$y \text{ moment of inertia} = I_{yy} = \sum_{i=1}^n [I_{yy_i} = m_i (cgz - cgz_i)^2],$$

$$z \text{ moment of inertia} = I_{zz} = \sum_{i=1}^n I_{zz_i}.$$

APPENDIX F  
SOURCE LISTING OF PROGRAM GEBOD

```

C--PROGRAM GEBOD-----(PERKIN-ELMER FTN VII)-----C
C   GEBOD GENERATES BODY DESCRIPTION DATA SETS FOR USE IN THE ARTICULATED C
C   TOTAL BCDY (ATB) MODEL.  USER HAS CHOICE OF PRODUCING A DATA SET C
C   CORRESPONDING TO ADULT MALE, ADULT FEMALE, OR A CHILD SUBJECT. C
C   THE BASIC GEOMETRY OF THE MODEL USED TO CALCULATE THE BODY DESCRIPTION C
C   DATA IS AN EXTENSIVELY MODIFIED VERSION OF THE MODEL USED BY C
C   PROGRAM GOOD (GENERATOR OF OCCUPANT DATA) WRITTEN BY CALSPAN C
C   CORP.  THE MODIFICATIONS TO THE MODEL AND THIS THE RESULTING C
C   PROGRAM, WERE WRITTEN BY THE UNIVERSITY OF DAYTON RESEARCH C
C   INSTITUTE UNDER CONTRACT F33613-81-C-0513 C
C
C   FILES: C
C     UNIT1--USER SUPPLIED DIMENSIONAL DATA. C
C     UNIT3--RESULTS READY FOR INSERTION INTO AN ATB MODEL INPUT DECK. C
C     UNITS (CRT OUTPUT)--INPUT PRCMPTS ARE WRITTEN TO THIS UNIT. C
C     UNIT7 (CRT INPUT)--SUBJECT DESCRIPTION IS ENTERED TO THIS UNIT. C
C     UNIT9 (PRINTER)--TABLE FORM OF RESULTS. C
C
C   ROUTINES (IN ORDER OF APPEARANCE): C
C     PROGRAM GE900 C
C     BLOCK DATA C
C     SUBROUTINE DIALOG C
C     SUBROUTINE ASKUN C
C     SUBROUTINE PTILE C
C     SUBROUTINE CONTAC C
C     SUBROUTINE SEGMAS C
C     SUBROUTINE SGINER C
C     SUBROUTINE ELLIP C
C     ENTRY ELLPMI C
C     SUBROUTINE TORSO C
C     SUBROUTINE FEET C
C     SUBROUTINE RESULTS C
C     SUBROUTINE CNVRT C
C-----C
C
C   PROGRAM GE900 C
C   COMMON /DIMS/ DD(-1:31),REGE2(24,-1:31),PRED(0:2) C
C   COMMON /FLOAT/ PI,PI2,PI4 C
C
C   CALL CARCCN (9,1)
C   PI = ACOS(-1.)
C   PI2 = PI + PI
C   PI4 = PI2 + PI2
C
10    CALL DIALOG (IPTR,ICNT,ISTRRT)
      IF (IPTR.LT.25) THEN
        DO 100 I = ISTRRT,31
          DD(I) = REGE2(IPTR+ICNT,I)
        DO 100 J = 0,ICNT - 1
100   DD(I) = DD(I) + PRED(J)*REGEQ(IPTR+J,I)
      ENDIF
C
      CALL CONTAC
      CALL SEGMAS
      CALL SGINER
      CALL RESULTS (ISTRRT)
      GOTO 10
      END
C--BLOCK DATA-----C
C   DATA IN COMMON AREAS C
C   /SGMNTS--SEGMENT DATA C

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C      ABCN--X, Y, AND Z CONTACT ELLIPSOID SEMIAxes FOR EACH SEGMENT
C      RMN--MASS OF EACH SEGMENT
C      PHI--SEGMENT MOMENTS OF INERTIA
C      XYZCG--LOCAL REFERENCE COORDINATES OF CENTER OF SEGMENT
C      CONTACT ELLIPSOIDS

C      /JNTS/--JOINT DATA
C      RNJ--LOCAL REFERENCE SYSTEM COORDINATES OF EACH JOINT. THIRD
C      SUBSCRIPT EQUAL TO 2 SPECIFIES LOCAL REFERENCE SYSTEM OF SEGMENT
C      J+1. A VALUE OF 1 IN THIS POSITION SPECIFIES LOCAL REFERENCE
C      SYSTEM OF SEGMENT JNT(J), WHERE IN BOTH CASES J IS THE VALUE OF
C      THE FIRST SUBSCRIPT.
C      JNT--POINTER ARRAY FOR ASSOCIATING JOINTS WITH SEGMENTS
C      YPRLL--YAW, PITCH, AND ROLL ANGLES OF JOINT AXES RELATIVE TO LOCAL
C      REFERENCE AXES
C      IPIN--SPECIFIES JOINT TYPE

C      /DIMS/--BODY DIMENSION DATA
C      DD--BODY DIMENSIONS
C      REGEQ--REGRESSION EQUATIONS USED TO COMPUTE BODY DIMENSIONS
C      PRED--VALUES OF PREDICTING VARIABLES TO BE USED WITH REGEQ
C      RANGE--ACCEPTABLE RANGE FOR PREDICTING VARIABLES
C      CONV--CONSTANTS FOR CONVERTING BODY DIMENSIONS FROM METRIC TO
C      ENGLISH UNITS

C      /NAMES/--CHARACTER STRINGS FOR VARIOUS LABLES
C      SUBTYP--DESCRIPTION TO USER OF 4 SOURCES OF BODY DIMENSION DATA
C      SEGLAB--SEGMENT LABLES
C      JNTLAB--JCINT LABLES
C      PLTSYM--PLOTTING SYMBOL FOR SEGMENTS AND JOINTS
C      DIMLAB--NAMES OF THE BODY DIMENSIONS
C      TITLE--RUN TITLE SUPPLIED BY THE USER
C      UNITS--UNITS FOR USER TO CHOOSE BETWEEN

C      /FLOAT/--VARIOUS CONSTANTS
C      PI--THE CONSTANT PI
C      PI2--PI**2
C      PI4--PI**4
C      DENS--DENSITY USED FOR COMPUTATION OF SEGMENT INERTIAL PROPERTIES
C      GRAV--ACCELERATION OF GRAVITY

C      /CYL/--DATA USED IN RIGHT ELLIPTICAL CYLINDER MODELLING OF SEGMENTS
C      FOR COMPUTATION OF INERTIAL PROPERTIES
C      ZESS--CONTAINS Z COORDINATE GIVING VERTICAL EXTENT OF CYLINDERS
C      ZH--HEIGHT OF EACH CYLINDER IN THE NUMERICAL INTEGRATION
C      NSEG--NUMBER OF CYLINDERS IN THE NUMERICAL INTEGRATION
C      CGZ--Z COORDINATE OF CENTER OF GRAVITY OF MODEL
C      WTCCR--WEIGHT CORRECTION FACTOR USED TO ADJUST DENS

C      ALL DATA WILL BE CALCULATED AND STORED IN ENGLISH UNITS
C      DD(-1)--MONTHS
C      DD(0)--PCUNDS
C      DD(1)--DD(31)--INCHES
C      DENS--SLUG/IN**3
C      GRAV--IN/SEC**2
C      RMN--SLUGS
C      PHI--SLUG*IN**2
C      ALL REMAINING LINEAR MEASUREMENTS ARE IN INCHES
C      THESE UNITS ARE UTILIZED UNTIL JUST PRIOR TO WRITING OUT OF RE-
C      SULTS. VALUES ARE THEN CONVERTED, IN PLACE, TO APPROPRIATE UNITS.
C      THE VALUE STORED IN GRAV IS USED FOR CONVERSION FROM SLUGS TO
C      POUNDS.

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BLOCK DATA
COMMON /SGMNTS/ ABCN(15,3),RMN(75),PHI(3,15),XYZCG(15,3)
COMMON /JNTS/ RHJ(5,28),JNT(16),YPRLL(14,6),IPIN(14)
COMMON /DIMS/ DD(-1:31),REGEQ(24,-1:31),PRED(3),
8           RANGE(2,-1:1,3),CONV(-1:1)
COMMON /NAMES/ SUBTYP(4),SEGLAB(15),JNTLAB(14),PLTSYM(29),
9           DIMLAB(-1:31),TITLE,UNITS(3,-1:2)
COMMON /FLOAT/ PI,PI2,PI4,DENS,GRAV
COMMON /CYL/ ZEES(0:15),ZH(15),NSEG(15),CGZ(15),WTCCR
CHARACTER SUBTYP*20,SEGLAB*3,JNTLAB*2,PLTSYM*1,DIMLAB*24,TITLE*60
CHARACTER UNITS*6

DATA SEGLAB//LT ','CT ','UT ','N ','H ','RUL','RLL',
8'RF ','LUL','LLL','LF ','RUA','RLA','LUA','LLA',
DATA JNTLAB/'P ','W ','NP','HP','RH','RK','RA',
8'LH','LK','LA','RS','RE','LS','LE ',
DATA PLTSYM/'1','2','3','4','5','6','7','8','9','A','B','C','D',
8'E','F','M','N','O','P','Q','R','S','T','U','V','W','X','Y','Z',
DATA JNT/1,2,3,4,1,6,7,1,9,10,3,12,3,14/
DATA SUBTYP /'CHILD (2 - 19 YEARS)', 'ADULT FEMALE',
8          'ADULT MALE', 'USER SUPPLIED DIM.'/
DATA UNITS /'MONTHS','YEARS',' ', 'LBS','KGRAMS','%TILE',
8          'IN','CM','%TILE','ENGLSH','METRIC',' '
DATA CONV /12.,2.2046,.39370/,DENS,GRAV/1.12287E-3,32.17405/

C DIMENSIONAL DATA LABELS
DATA DIMLAB /
8   'AGE'                   '/WEIGHT
8   'STANDING HEIGHT'      '/SHOULDERR HEIGHT
8   'ARMPIT HEIGHT'        '/WAIST HEIGHT
8   'SEATED HEIGHT'        '/HEAD LENGTH
8   'HEAD BREADTH'         '/HEAD TO CHIN HEIGHT
8   'NECK CIRCUMFERENCE'   '/SHOULDERR BREADTH
8   'CHEST DEPTH'          '/CHEST BREADTH
8   'WAIST DEPTH'          '/WAIST BREADTH
8   'BUTTOCK DEPTH'         '/HIP BREADTH,STANDING
8   'SHOULDER TO ELBOW LENGTH' /FOREARM-HAND LENGTH
8   'BICEPS CIRCUMFERENCE'  '/ELBOW CIRCUMFERENCE
8   'FOREARM CIRCUMFERENCE' /WRIST CIRCUMFERENCE
8   'KNEE HEIGHT,SEATED'    '/THIGH CIRCUMFERENCE
8   'UPPER LEG CIRCUMFERENCE' /KNEE CIRCUMFERENCE
8   'CALF CIRCUMFERENCE'    '/ANKLE CIRCUMFERENCE
8   'ANKLE HEIGHT,OUTSIDE'  '/FOOT BREADTH
8   'FOOT LENGTH'           '/

DATA RANGE /
2 26.00   , 260.0   , 22.27   , 247.6   , 32.01   , 76.54   ,
2 18.50   , 56.50   , 35.00   , 200.0   , 56.93   , 72.05   ,
2 21.50   , 50.50   , 118.0   , 264.0   , 62.17   , 77.64   ,
DATA (REGEQ(J,-1), J=1,24) /
6 1.000   , .4547E-12, 1.213   , 25.43   , 5.202   , -158.9   ,
8 1.000   , 0.       , 0.       , .4547E-12, 0.       , 0.       ,
30.      , 0.       , 0.       , 0.       , 0.       , 0.       ,
30.      , 0.       , 0.       , 0.       , 0.       , 0.       ,
DATA (REGEQ(J, 0), J=1,24) /
8 .6625   , -.7660   , 1.000   , .4547E-12, 3.743   , -122.2   ,
20.      , 1.000   , 0.       , .4547E-12, 1.000   , .4547E-12,
8 3.737   , -111.2   , 1.000   , 0.       , .4547E-12, 1.000   ,
8 .9095E-12, 4.530   , -142.7   , 1.000   , 0.       , .9095E-12,
DATA (REGEQ(J, 1), J=1,24) /
8 .1756   , 32.62   , .2314   , 35.58   , 1.000   , .2274E-12,
8 0.       , 0.       , 1.000   , .2274E-12, .7539E-01, 54.16   ,
8 1.000   , .2274E-12, 0.       , 1.000   , .2274E-12, .5850E-01,

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8 59.56 , 1.000 , .4547E-12,0. , 1.000 , .4547E-12/
DATA (REGEQ(j, 2), j=1,24) /
8.1518 , 24.79 , .1994 , 27.37 , .3721 , -3.398 ,
80. , 0. , .8721 , -3.398 , .7182E-01, 42.77 ,
& .8751 , -3.936 , .7555E-02, .3469 , -3.096 , .5344E-01,
& 67.02 , .8911 , -5.049 , .8583E-02, .8522 , -3.824 ,
DATA (REGEQ(j, 3), j=1,24) /
8.1467 , 22.53 , .1916 , 25.19 , .3315 , -4.669 ,
80. , -1.1217E-01, .8770 , -5.954 , .5840E-01, 39.83 ,
& .8309 , -5.762 , -.6495E-02, .8551 , -6.484 , .4637E-01,
& 43.06 , .8398 , -7.529 , -.3761E-02, .8569 , -8.066 ,
DATA (REGEQ(j, 4), j=1,24) /
8.1186 , 17.74 , .1530 , 19.97 , .6922 , -4.726 ,
80. , -1.1855E-01, .7519 , -7.012 , .5302E-01, 32.73 ,
& .6845 , -4.206 , 0. , .6845 , -4.206 , .3642E-01,
& 35.39 , .7043 , -7.256 , -.6506E-02, .7338 , -9.185 ,
DATA (REGEQ(j, 5), j=1,24) /
8.7904E-01, 19.17 , .1047 , 20.34 , .4412 , 4.849 ,
& .5848E-02, .1910E-01, .3393 , 8.114 , .3620E-01, 29.09 ,
& .6225 , 6.734 , .5773E-02, .4010 , 7.376 , .2664E-01,
& 32.06 , .6043 , 8.460 , .4060E-02, .3859 , 9.039 ,
DATA (REGEQ(j, 6), j=1,24) /
& .3642E-02, 6.831 , .5571E-02, 6.881 , .2249E-01, 6.110 ,
& -3.975E-02, .2793E-02, .3264E-01, 5.825 , .4897E-02, 6.625 ,
& .3600E-01, 6.950 , .3021E-02, .2471E-01, 5.296 , .3209E-02,
& 7.266 , .2680E-01, 5.952 , .2233E-02, .1668E-01, 6.271 ,
DATA (REGEQ(j, 7), j=1,24) /
& .3642E-02, 5.220 , .5337E-02, 5.237 , .2096E-01, 4.532 ,
& -6.671E-03, .3641E-02, .1071E-01, 4.873 , .4089E-02, 5.194 ,
& .1347E-01, 6.853 , .4089E-02, 0. , 5.194 , .3060E-02,
& 5.611 , .1174E-01, 5.322 , .3060E-02, 0. , 5.611 ,
DATA (REGEQ(j, 8), j=1,24) /
& .8988E-02, 6.582 , .1266E-01, 6.666 , .5203E-01, 4.867 ,
& -2.157E-02, .4550E-02, .4621E-01, 5.080 , .7362E-02, 7.688 ,
& .6816E-01, 6.275 , .3057E-02, .5674E-01, 4.615 , .3143E-02,
& 8.420 , .4659E-01, 5.712 , 0. , .4659E-01, 5.712 ,
DATA (REGEQ(j, 9), j=1,24) /
& .2281E-01, 8.421 , .3449E-01, 8.448 , .1301 , 4.177 ,
& -2.812E-02, .3292E-01, .2141E-01, 7.760 , .2316E-01, 10.34 ,
& .8900E-01, 7.607 , .2316E-01, 0. , 10.34 , .2644E-01,
& 10.85 , .6527E-01, 10.54 , .2306E-01, -.6185E-01, 14.54 ,
DATA (REGEQ(j, 10), j=1,24) /
& .3595E-01, 7.530 , .4866E-01, 8.020 , .2040 , .8749 ,
& .4037E-02, .1483E-01, .1271 , 3.354 , .1927E-01, 11.66 ,
& .1246 , 6.160 , .1369E-01, .7344E-01, 7.582 , .1612E-01,
& 13.24 , .1181 , 7.790 , .1253E-01, .6133E-01, 9.578 ,
DATA (REGEQ(j, 11), j=1,24) /
& .2970E-01, 5.225 , .4249E-01, 5.333 , .1620 , -.2418E-01,
& 50. , .3764E-01, .2091E-01, 6.539 , .3612E-01, 4.965 ,
& .7300E-01, 6.650 , .3989E-01, -.7607E-01, 9.086 , .2690E-01,
& 4.984 , .6114E-01, 5.386 , .3174E-01, -.8265E-01, 9.915 ,
DATA (REGEQ(j, 12), j=1,24) /
& .2699E-01, 5.195 , .3856E-01, 5.411 , .1504 , .3666 ,
& .4513E-02, .2798E-01, .2213E-01, 4.506 , .3185E-01, 6.968 ,
& .8875E-01, 5.357 , .3505E-01, -.4222E-01, 9.255 , .2911E-01,
& 7.854 , .8877E-01, 6.709 , .3234E-01, -.9866E-01, 11.35 ,
DATA (REGEQ(j, 13), j=1,24) /
& .1284E-01, 5.024 , .2279E-01, 4.763 , .7598E-01, 2.485 ,
& -8.176E-02, .3995E-01, -.3147E-01, 6.097 , .2922E-01, 2.979 ,
& .5358E-01, 3.279 , .3511E-01, -.7761E-01, 7.183 , .3026E-01,
& 3.528 , .5167E-01, 5.174 , .3706E-01, -.1162 , 10.46 ,
DATA (REGEQ(j, 14), j=1,24) /
& .2718E-01, 5.367 , .3977E-01, 5.508 , .1522 , .4650 ,

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8 .3925E-02, .3503E-01, 0. , .5406 , .3527E-01, 5.C10
6 .1C60 , .2734 , .380CE-01, -.3598E-01, 6.959 , .3741E-01,
8 5.694 , .1105 , .4.473 , .4211E-01, -.8025E-01, 10.48 /
DATA (REGEQ(J,15), J=1,26) /
8 .2730E-01, 4.812 , .4032E-01, 4.910 , .1529 , -.1220 ,
8 .4893E-02, .3874E-01, -.1900E-01, 5.666 , .3419E-01, 3.976 ,
8 .7090E-01, 3.803 , .4021E-01, -.7937E-01, 8.275 , .3077E-01,
8 4.095 , .6978E-01, 4.566 , .3632E-01, -.9475E-01, 9.749 /
DATA (REGEQ(J,16), J=1,26) /
8 .3552E-01, 5.542 , .4957E-01, 5.905 , .1968 , -.7718 ,
8 .1151E-01, .3192E-01, .1642E-01, 9.020 , .4092E-01, 8.610 ,
8 .1285 , .3.563 , .4294E-01, -.3192E-01, 10.34 , .2803E-01,
8 9.019 , .1258 , .5.100 , .2903E-01, 0. , 9.019 /
DATA (REGEQ(J,17), J=1,26) /
8 .3933E-01, 6.369 , .5175E-01, 7.038 , .2237 , -.9239 ,
8 .8433E-03, 0. , .2193 , .-7898 , .1702E-01, 10.04 ,
8 .1962 , .-3163 , .2976E-02, .1851 , .1459E-01, .1256E-01,
8 11.97 , .2087 , .-6158 , 0. , .2087 , .-6158 /
DATA (REGEQ(J,18), J=1,26) /
8 .4900E-01, 8.421 , .6536E-01, 9.182 , .2E04 , -.7587 ,
8 -.2689E-02, .4490E-02, .2776 , .-6374 , .2C92E-01, 13.78 ,
8 .2478 , .6324 , .296CE-02, .2367 , .9615 , .1671E-01,
8 16.54 , .2646 , .9735 , .1677E-02, .2370 , .1.213 /
DATA (REGEQ(J,19), J=1,26) /
8 .2664E-01, 4.976 , .4173E-01, 4.872 , .1501 , .1143 ,
8 .5211E-01, -.6492E-01, 6.478 , .4369E-01, 4.522 ,
8 .5386E-01, 6.646 , .5528E-01, -.1527 , .12.79 , .3340E-01,
8 6.608 , .5996E-01, 8.219 , .4067E-01, -.1243 , .14.02 /
DATA (REGEQ(J,20), J=1,26) /
8 .2267E-01, 5.152 , .3434E-01, 5.166 , .1290 , .9440 ,
8 -.1938E-02, .3358E-01, .1344E-01, 4.738 , .2421E-01, 7.539 ,
8 .1221 , .2.826 , .2086E-01, .4420E-01, 5.145 , .1919E-01,
8 8.967 , .1061 , .4.894 , .1767E-01, .2601E-01, 7.416 /
DATA (REGEQ(J,21), J=1,26) /
8 .2267E-01, 5.152 , .3434E-01, 5.166 , .1290 , .9440 ,
8 -.1938E-02, .3358E-01, .1344E-01, 4.738 , .2643E-01, 5.879 ,
8 .7088E-01, 4.719 , .2938E-01, -.3890E-01, 7.986 , .2116E-01,
8 7.411 , .6768E-01, 6.359 , .2341E-01, -.3835E-01, 9.700 /
DATA (REGEQ(J,22), J=1,26) /
8 .1143E-01, 3.971 , .1771E-01, 3.951 , .6620E-01, 1.791 ,
8 -.3479E-02, .1804E-01, .1674E-01, 3.647 , .1090E-01, 4.503 ,
8 .5371E-01, 2.463 , .9530E-02, .1810E-01, 3.523 , .9921E-02,
8 5.202 , .5166E-01, 3.317 , .9386E-02, .9137E-02, 4.657 /
DATA (REGEQ(J,23), J=1,26) /
8 .3917E-01, 9.584 , .7857E-01, 10.55 , .3433 , -.1.746 ,
8 -.8680E-02, -.4527E-02, .4045 , .-3.654 , .3002E-01, 14.98 ,
8 .3345 , .-2.547 , .6469E-02, .3104 , .-1.829 , .2467E-01,
8 17.67 , .3558 , .-2.389 , .5264E-02, .3321 , .-2.141 /
DATA (PEGEQ(J,24), J=1,24) /
8 .6066E-01, 9.311 , .8944E-01, 9.551 , .3382 , .-1.560 ,
8 .1018E-01, .8338E-01, -.2709E-01, 10.25 , .8417E-01, 11.13 ,
8 .1869 , .9.912 , .9769E-01, -.1781 , .20.77 , .6998E-01,
8 11.01 , .1614 , .11.89 , .8237E-01, -.2117 , .23.64 /
DATA (REGEQ(J,25), J=1,24) /
8 .4805E-01, 7.998 , .7076E-01, 8.195 , .2691 , -.6787 ,
8 .5930E-02, .6358E-01, 0. , .8.043 , .6412E-01, 9.905 ,
8 .1664 , .7.448 , .7187E-01, -.1022 , .15.44 , .3229E-01,
8 9.621 , .1412 , .5.370 , .3229E-01, 0. , .9.621 /
DATA (REGEQ(J,26), J=1,24) /
8 .4805E-01, 7.998 , .7076E-01, 8.195 , .2691 , -.6787 ,
8 .5930E-02, .6358E-01, 0. , .8.043 , .4406E-01, 8.684 ,
8 .1458 , .4.985 , .4605E-01, -.2626E-01, 10.11 , .3334E-01,
8 9.686 , .1512 , .4.916 , .3334E-01, 0. , .9.686 /

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DATA (REGEQ(J,27), J=1,24) /
3 .3564E-01, 6.685 , .5209E-01, 6.839 , .1998 , .2129 ,
3 .1539E-02, .4370E-01, .2325E-01, 5.794 , .4012E-01, 8.335 ,
3 .1106 , 6.386 , .4429E-01,-.5493E-01, 11.31 , .3250E-01,
3 9.002 , .8942E-01, 8.469 , .3718E-01,-.8000E-01, 13.77 /
DATA (REGEQ(J,28), J=1,24) /
3 .1770E-01, 5.116 , .2659E-01, 5.152 , .1016 , 1.786 ,
3 -.3664E-02, .2284E-01, .3523E-01, 3.995 , .1809E-01, 3.999 ,
3 .7603E-01, 3.649 , .1720E-01, .1177E-01, 5.361 , .1610E-01,
3 6.028 , .6599E-01, 4.216 , .1665E-01,-.9456E-02, 6.593 /
DATA (REGEQ(J,29), J=1,24) /
3 .6837E-02, 1.319 , .9232E-02, 1.417 , .4015E-01,-.2052E-01,
3 -.1302E-02, 0. , .4697E-01,-.2305 , .3434E-02, 2.230 ,
3 .4163E-01, .9788E-02, 0. , .4163E-01, .9788E-02, .4310E-02,
3 6.652 , .8736E-01,-.6990 , -.1090E-02, .9230E-01,-.8545 /
DATA (REGEQ(J,30), J=1,24) /
3 .8742E-02, 2.193 , .1221E-01, 2.283 , .5052E-01, .5281 ,
3 -.1722E-02, .4119E-02, .4407E-01, .7576 , .4638E-02, 2.901 ,
3 .2947E-01, 1.611 , .3353E-02, .1694E-01, 1.986 , .4136E-02,
3 3.127 , .3618E-01, 1.459 , .2907E-02, .2101E-01, 1.873 /
DATA (REGEQ(J,31), J=1,24) /
3 .2436E-01, 5.384 , .3275E-01, 5.742 , .1415 , .7017 ,
3 -.5737E-02, 0. , .1715 , -.2125 , .1365E-01, 7.738 ,
3 .1299 , 1.186 , .5296E-02, .1101 , 1.775 , .1028E-01,
3 8.858 , .1309 , 1.502 , .3570E-02, .1148 , 2.012 /

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C YAW, PITCH AND ROLL

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DATA YPRLL/
3 14*0.,30.,0.,0.,30.,0.,90.,45.,0.,90.,45.,0.,60.,0.,60.,
3 32*0.,-90.,-45.,-90.,-90.,-65.,-90.,15.,0.,15.,15*0./
DATA IPIN/C,0,0,0,0,1,0,0,1,0,0,1,0,1/
END

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C--SUBROUTINE DIALOG-----C

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C DIALOG WRITES PROMPTS TO THE CRT AND ACCEPTS INPUT FROM THE CRT
C DESCRIBING THE SUBJECT FOR WHICH BODY DESCRIPTION DATA IS TO BE
C PRODUCED. THE PARAMETERS, IPTR, ICNT, AND ISTAT, ARE RETURNED TO THE
C MAIN ROUTINE SPECIFYING THE CHOICES MADE BY THE USER
C IPTR--SPECIFIES ROW OF REGEQ CONTAINING FIRST REGRESSION EQUATION
C COEFFICIENT TO BE USED. IPTR IS SET TO 25 FOR USER SUPPLIED
C DIMENSIONAL DATA.
C ICNT--NUMBER OF COEFFICIENTS IN THE REGRESSION EQUATION TO BE USED.
C ISTAT--FIRST BODY DIMENSION TO BE GENERATED:
C      ISTAT = 1 (AGE) FOR CHILD SUBJECTS
C      ISTAT = 0 (WEIGHT) FOR ADULT SUBJECTS OR USER SUPPLIED DATA
C      VALUES ARE ALSO READ INTO PRED FOR THE PREDICTING VARIABLES
-----C

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SUBROUTINE DIALOG (IPTR,ICNT,ISTRT)
COMMON /DIVS/ DU(-1:31),REGEQ(24,-1:31),PRED(-1:1),
              RANGE(2,-1:1,3),CCNV(-1:1)
COMMON /NAMES/ SUBTYP(4),SEGLAB(15),JNTLAB(14),PLTSYM(29),
              DIMNM(-1:31),TITLE,UNITS(3,-1:2)
CHARACTER SUBTYP*20,SEGLAB*3,JNTLAB*2,PLTSYM*1,ANS*1,DIMNM*24
CHARACTER TITLE*60,UNITS*6,CLR(7)*6
INTEGER IPTMAT(-1:2,3),IPTZ(13)
EQUIVALENCE (IPTMAT,IPTZ)
DATA IPTZ /1,3,5,7,11,11,13,15,18,18,20,22,25/
DATA CLR /218583F32,26C1B4818,24A183C0C,200194800,3*20/

WRITE (5,11) CLR
WRITE (5,22)
READ (7,333) TITLE
WRITE (5,11) CLR

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        WRITE (5,333) ' //TITLE
        WRITE (9,333) '1//TITLE

10     WRITE (5,33) (I,SUBTYP(I),I=1,6)
        WRITE (5,44)
        READ (7,222) ISUB
        IF (ISUB.GT.4 .OR. ISUB.LT.1) GOTO 10
        WRITE (9,333) '0//SUBTYP(ISUB)
        ISTRT = -1
        IF (ISUB.GT.1) ISTRT = 0
        IF (ISUB.GT.3) GOTO 100

        WRITE (5,11) CLR
        WRITE (5,333) ' //TITLE
        WRITE (5,33) (I+1,DIMNM(I),I=ISTRT,1),3,'ALL OF THE ABOVE'
        WRITE (5,55)
        READ (7,222) IDIM
        IDIM = IDIM -1
        IF (IDIM.LT.ISTRT .OR. IDIM.GT.2) GOTO 20
        IF (IDIM.GE.2) THEN
          LPSTRT = ISTRT
          LPEND = 1
        ELSE
          LPSTRT = IDIM
          LPEND = LPSTRT
        ENDIF

        WRITE (5,11) CLR
        WRITE (5,333) ' //TITLE
        WRITE (9,555)
        DO 50 I = LPSTRT,LPEND
          CALL ASKUN (DIMNM(I),UNITS(1,I),ICHOS,ISTRT+3)
          IF (ICHOS.GE.3) THEN
            CALL PTILE (ISUB,I,PRED(I))
          ELSE
            TCONV = 1.
            IF (ICHOS.GE.2) TCONV = CONV(I)
          ENDIF
          WRITE (5,77) DIMNM(I),(RANGE(J,I,ISUB)/TCONV,J=1,2)
          READ (5,444) PRED(I)
          WRITE (9,666) DIMNM(I),PRED(I),UNITS(ICHOS,I)
          PRED(I) = PRED(I)*TCONV
          IF ((PRED(I)-RANGE(1,I,ISUB))*(PRED(I)-RANGE(2,I,ISUB)) .GT. 0.) GOTO 40
        50   CONTINUE

        IF (IDIM.LT.2) THEN
          PRED(-1) = PRED(IDIM)
        ELSE
          IF (ISUB.GT.1) THEN
            DO 60 I=-1,0
              PRED(I) = PRED(I+1)
            ENDIF
          ENDIF
          IPTR = IPTMAT(IDIM,ISUB)
          ICNT = IPTMAT(IDIM+1,ISUB) - IPTR - 1
          WRITE (5,11) CLR
          WRITE (5,333) ' //TITLE
          RETURN

100    WRITE (5,88)
          READ (7,333) ANS
          IF (ANS.EQ.'N') STOP 'FROM DIALOG'

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IF (ANS.NE.'Y') GOTO 100
READ (1,99) (DD(I),I=0,31)
IPTR = 25
CALL ASKUN(SUBTYP(4),UNITS(1,2),ICHOS,2)
IF (ICHOS.GE.2) THEN
    DD(0) = DD(0)*CONV(0)
    DO 120 I=1,31
        DD(I) = DD(I)*CONV(1)
120
ENDIF
RETURN

11  FORMAT (7A6)
22  FORMAT (' PROGRAM GEBOD'/' GEBOD GENERATES BODY DESCRIPTION',
9      ' DATA'/' SUITABLE FOR INPUT TO THE ATB MODEL',
&      ' PLEASE ENTER A DESCRIPTION OF THE SUBJECT' ,
2      ' (<60 CHARS.)')
33  FORMAT (/(I12,'')/3X,A/))
44  FORMAT (' ENTER NUMBER CORRESPONDING TO DESIRED SUBJECT TYPE')
55  FORMAT (' ENTER NUMBER CORRESPONDING TO '/* PREDICTING',
3      ' DIMENSION(S) TO BE SUPPLIED')
77  FORMAT (' ENTER VALUE FOR ',A26/' IN THE RANGE ',G10.4,'.',G10.4)
38  FORMAT (' TO UTILIZE EXTERNAL DIMENSIONAL DATA, THE DATA MUST BE',
2      ' IN THE PROPER FORMAT AND IN A FILE ASSIGNED TO UNIT 1',
2      ' HAS THE ABOVE BEEN SATISFIED (Y/N) ?')
99  FORMAT (8F1G.0)
222 FORMAT (B4,I60)
333 FORMAT (A)
444 FORMAT (G6G.0)
555 FORMAT ('SELECTED BODY DIMENSIONS')
666 FORMAT (A40,G15.4,A6)
END

C--SUBROUTINE ASKUN-----
C   ASKUN ASKS USER CHOICE OF UNITS TO BE USED WITH SOME INPUT VARIABLE
C   OR THE OUTPUT OF RESULTS.  THE PARAMETERS ARE THE FOLLOWING:
C     VARS--CHARACTER STRING DESCRIBING WHAT UNITS ARE TO BE SELECTED FOR
C     UNITS--UNITS AVAILABLE TO CHOOSE FROM
C     ICHOS--RETURNS WHICH OF THE UNITS WAS CHOSEN
C     ICNT--NUMBER OF DIFFERENT UNITS AVAILABLE TO CHOOSE FROM
C-----C

SUBROUTINE ASKUN (VARS,UNITS,ICHOS,ICNT)
CHARACTER VARS*(*),UNITS(ICNT)*6,UNITIN*6

30  WRITE (5,66) VARS
44  WRITE (5,55) (I,UNITS(I),I=1,ICNT)
READ (7,44) ICHOS
IF ( (ICHOS-1)*(ICHOS-ICNT) .GT. 0) GOTO 30

RETURN
66  FORMAT (B4,I60)
99  FORMAT (I10,''),5X,A)
60  FORMAT (' SELECT UNITS FOR ',A)
END

C--SUBROUTINE PTILE-----
C   PTILE COMPUTES A PERCENTILE POINT, SPECIFIED BY THE USER, OF A BODY
C   DIMENSION USED AS A PREDICTOR, BY ASSUMING THE DIMENSION IS
C   NORMALLY DISTRIBUTED.  THE PARAMETERS ARE THE FOLLOWING:
C     ISUB--SPECIFIES SUBJECT TYPE, AND THUS WHICH POSITION OF THE
C           MEAN AND STANDARD ARRAYS TO USE.
C     IDIM--THE DIMENSION A PERCENTILE POINT IS TO BE COMPUTED FOR
C     PRED--RETURNS THE COMPUTED PERCENTILE POINT
C     NOTE: THIS ROUTINE REQUIRES USE OF IMSL ROUTINE MDNRIS
C-----C

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SUBROUTINE PTILE (ISUB, IDIM, PRED)
COMMON /NAMES/ SUBTYP(4), SEGLAB(15), JNTLAB(14), PLTSYM(29),
& DIMNM(-1:31), TITLE, UNITS(3,-1:1)
REAL MEAN(C:1,2:3), STDEV(0:1,2:3)
CHARACTER SUBTYP*20, SEGLAB*3, JNTLAB*2, PLTSYM*1, DIMNM*24
CHARACTER TITLE*60, UNITS*6
DATA MEAN, STDEV/127.24, 63.82, 173.54, 69.82, 16.57, 2.36, 21.42, 2.64/
10  WRITE (5,111) DIMNM(IDIM)
READ (7,99) PCENT
IF ( (PCENT-1.)*(PCENT-100.) .GE. 0.) GOTO 10
WRITE (9,222) DIMNM(IDIM), PCENT
PCENT = PCENT/100.

CALL NOTRI (PCENT, X, D, IER)
PRED = MEAN(IDIM, ISUB) + X*STDEV(IDIM, ISUB)

RETURN
99  FORMAT (F40.0)
111 FORMAT (' ENTER DESIRED PERCENTILE FOR ',A/
& ' (A REAL VALUE BETWEEN 0. AND 100.)')
222 FORMAT (A40,615.6,'%-TILE')
END

C--SUBROUTINE NOTRI-----
C  NOTRI COMPUTES X (THE OUTPUT ARGUMENT SUCH THAT P=X) THE
C  PROBABILITY THAT U, THE RANDOM VARIABLE, IS LESS THAN OR EQUAL
C  TO X.), D (THE OUTPUT DENSITY,F(X).), AND IER (THE OUTPUT
C  ERROR CODE.) USING P (THE INPUT PROBABILITY.). C
C-----C

      SUBROUTINE NOTRI(P,X,D,IE)
C
IE=0
X=.99999E+74
D=X
IF(P)1,4,2
1 IE=-1
GO TO 12
2 IF (P-1.0)7,5,1
4 X=-.999999E+74
5 D=0.0
GO TO 12
C
7 D=P
IF(D=0.5)9,9,8
8 D=1.0-D
9 T2=ALOG(1.0/(D*D))
T=SQRT(T2)
X=T-(2.515517+0.802853*T+0.010328*T2)/(1.0+1.432758*T+0.189269*T2
& +0.001308*T*T2)
IF(P=0.5)10,10,11
10 X=-X
11 D=0.3989423*EXP(-X*X/2.0)
12 RETURN
END

C--SUBROUTINE CONTAC-----
C  CONTAC COMPUTES JOINT LOCATIONS AND CONTACT ELLIPSOID SEMIAxes. C
C-----C

SUBROUTINE CONTAC
COMMON /FLOAT/ PI,PI2,PI6
COMMON /SGMNTS/ AN(15), BN(15), CN(15), RMN(15), PHI(3,15), XYZCG(15,3)

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COMMON /JNTS/ RNJ(3,28)
COMMON /DIMS/ DD(-1:31)

C THE CENTERS OF GRAVITY AND JOINT X,Y COORDINATES ARE ALL SET TO ZERO.
DO 10 J=1,3
DO 10 I=1,15
10 XYZCG(I,J)=0.0
DO 20 J=1,2
DO 20 I=1,22
20 RNJ(J,I)=0.0

C NON-ZERO X,Y JOINT COORDINATES ARE COMPUTED.
RNJ(1,21)=DD(29)*0.5
RNJ(1,24)=RNJ(1,21)
RNJ(2,5)=0.5*(DD(16)-DD(24)/PI)
RNJ(2,8)=-RNJ(2,5)
RNJ(2,11)=0.5*(DD(10)-DD(19)/PI)
RNJ(2,13)=-RNJ(2,11)

C SMW IS ONE HALF THE HEIGHT OF THE ABDOMEN SEGMENT.
C OLAP IS USED AS AN OVERLAP AMOUNT BETWEEN CERTAIN CONTACT ELLIPSOIDS.
SMW = (DD(2) - DD(4))/10.
OLAP = DD(9)/PI

C Z COORDINATES OF JOINTS ARE COMPUTED RELATIVE TO SEGMENT JNT(J),
C WHERE J IS THE SECOND SUBSCRIPT OF RNJ
RNJ(3,1) = (DD(1) - DD(5) - DD(4) + SMW)/2.
RNJ(3,2) = -SMW
RNJ(3,3) = -9.*SMW/2.
RNJ(3,6) = (DD(8) + DD(2) - DD(1) + OLAP/2.)/2.
RNJ(3,5) = (DD(4) - SMW - DD(1) + DD(3) - DD(24)/PI)/2.
RNJ(3,6)=0.5*(DD(1)-DD(5)-DD(23)+DD(24)/PI)
RNJ(3,7)=0.5*(DD(23)-DD(29)-DD(28)/PI2)
RNJ(3,8) = RNJ(3,5)
RNJ(3,9)=RNJ(3,6)
RNJ(3,10)=RNJ(3,7)
RNJ(3,11)=-DD(2)+DD(3)+DD(19)/PI2
RNJ(3,12)=0.5*(DD(17)-DD(20)/PI)
RNJ(3,13)=RNJ(3,11)
RNJ(3,16)=RNJ(3,12)

C Z COORDINATES OF JOINTS ARE COMPUTED RELATIVE TO SEGMENT J-13,
C WHERE J IS THE SECOND SUBSCRIPT OF RNJ
RNJ(3,15) = SMW
RNJ(3,16) = -RNJ(3,3)
RNJ(3,17) = (DD(1) - DD(8) - DD(2) - OLAP/2.)/2.
RNJ(3,18) = DD(8) /2. + OLAP/4.
RNJ(3,19)=0.5*(-DD(1)+DD(3)+DD(23)-DD(26)/PI)
RNJ(3,20) = (DD(29) - DD(23) - DD(28)/PI2 + DD(25)/PI)/2.
RNJ(3,21) = DD(23)/PI2 - DD(31)/2.
RNJ(3,22)=RNJ(3,19)
RNJ(3,23)=RNJ(3,20)
RNJ(3,24)=RNJ(3,21)
RNJ(3,25)=0.5*(DD(19)/PI-DD(17))
RNJ(3,26)=0.5*(DD(20)/PI-DD(18))
RNJ(3,27)=RNJ(3,25)
RNJ(3,28)=RNJ(3,26)

C SEGMENT CONTACT ELLIPSOID X SEMIAxes ARE COMPUTED.
AN(5)=DD(6)*0.5
AN(4)=DD(9)/PI2
AN(3)=DD(11)*0.5
AN(2)=DD(13)*0.5

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AN(1)=DD(15)*0.5
AN(6)=(DD(24)+DD(25))/PI2
AN(7)=DD(27)/PI2
AN(8)=DD(29)*0.5
AN(9)=4N(6)
AN(10)=AN(7)
AN(11)=AN(8)
AN(12)=DD(19)/PI2
AN(13)=DD(21)/PI2
AN(14)=AN(12)
AN(15)=AN(13)

C SEGMENT CONTACT ELLIPSOID Y SEMIAxes ARE COMPUTED.
BN(5)=DD(7)*0.5
BN(4)=AN(4)
BN(3)=DD(12)*0.5
BN(2)=DD(14)*0.5
BN(1)=DD(16)*0.5
BN(6)=AN(6)
BN(7)=AN(7)
BN(8)=DD(30)*0.5
BN(9)=AN(9)
BN(10)=AN(10)
BN(11)=BN(8)
BN(12)=AN(12)
BN(13)=AN(13)
BN(14)=AN(14)
BN(15)=AN(15)

C SEGMENT CONTACT ELLIPSOID Z SEMIAxes ARE COMPUTED.
CN(5) = (DD(8) + OLAP/2.)/2.
CN(4) = (DD(1) - DD(8) - DD(2) + OLAP/2.)/2.
CN(3) = 9.*SMW/2.
CN(2) = SMW + OLAP/2.
CN(1) = (DD(6)+DD(5)-DD(1) - SMW)*0.5
CN(6)=(DD(1)-DD(5)-DD(23)+DD(24)/PI+DD(26)/PI)*0.5
CN(7)=(DD(23)-DD(29)+DD(28)/PI2)*0.5
CN(3)=DD(31)*0.5
CN(9)=CN(6)
CN(10)=CN(7)
CN(11)=CN(8)
CN(12)=DD(17)*0.5
CN(13)=DD(18)*0.5
CN(14)=CN(12)
CN(15)=CN(13)

C THE GLOBAL LOCATION OF SEGMENT CENTERS IS PLACED IN XYZCG FOR
C SEGMENTS THAT WILL USE ELLIP IN COMPUTATION OF MASS AND
C MOMENTS OF INERTIA.
XYZCG(1,3) = (DD(4) - SMW + DD(1) - DD(5))/2.
XYZCG(2,3) = DD(4)
XYZCG(3,3) = DD(2) - 9.*SMW/2.
XYZCG(8,3) = DD(29) - DD(31)/2. + DD(28)/PI2
XYZCG(11,3) = XYZCG(3,3)

RETURN
END
C--SUBROUTINE SEGMAS-----
C   SEGMAS COMPUTES APPROXIMATE SEGMENT MASSES. WTCOR IS THEN COMPUTED      C
C   TO ADJUST BODY DENSITY, DENS, SO THAT TOTAL BODY MASS AGREES            C
C   WITH DD(0). SEGMENT MASSES ARE THEN RECOMPUTED USING WTCOR.          C
-----C

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SUBROUTINE SEGMAS
EXTERNAL TORSO, FEET
COMMON /FLOAT/ PI,PI2,PI4,DENS,GRAV
COMMON /CYL/ ZEES(0:15),ZH(15),NSEG(15),CGZ(15),WTCCR
COMMON /JNTS/ RNJ(3,29)
COMMON /SGMNTS/ ABCN(15,3),RMN(15),PHI(45),XYCG(30),ZCG(15)
COMMON /DIMS/ DD(-1:31)
REAL AN(15),BN(15),CN(15)
EQUIVALENCE (AN,ABCN),(BN,ABCN(1,2)),(CN,ABCN(1,3))
SUMM=0.0

C POSITIONS 0 THRU 3 OF ZEES DEFINE THE VERTICAL LIMITS OF TCRSO
C SEGMENTS. 10 THRU 11 DEFINE THE LIMITS OF THE FEET.
SMW = (DD(2) - DD(4))/10.
ZEES(0) = DD(1) - DD(5)
ZEES(1) = DD(4) - SMW
ZEES(2) = DD(4) + SMW
ZEES(3) = DD(2)
ZEES(11) = DD(29) + DD(28)/PI2
ZEES(10) = ZEES(11) - DD(31)
DO 5 I = 1,3
    CALL ELLIP (I,TORSO,RMN(I))
    ZCG(I) = CGZ(I) - ZCG(I)
    SUMM = SUMM + RMN(I)
5   CALL ELLIP (11,FEET,RMN(11))
    SUMM = SUMM + 2.*RMN(11)
    RMN(5) = RMN(11)
    ZCG(11) = CGZ(11) - ZCG(11)
    ZCG(8) = ZCG(11)
    DO 7 I = 1,3
        RNJ(3,I) = RNJ(3,I) + ZCG(I)
7     RNJ(3,15) = ZCG(2) + RNJ(3,15)
    RNJ(3,16) = ZCG(3) + RNJ(3,16)
    RNJ(3,5) = ZCG(1) + RNJ(3,5)
    RNJ(3,8) = ZCG(1) + RNJ(3,8)
    RNJ(3,11) = RNJ(3,11) + ZCG(3)
    RNJ(3,13) = RNJ(3,13) + ZCG(3)
    RNJ(3,21) = RNJ(3,21) + ZCG(8)
    RNJ(3,24) = RNJ(3,24) + ZCG(11)
    DO 10 I = 4,7
        RMN(I) = 4.0/3.0*PI*AN(I)*BN(I)*CN(I)*DENS
        SUMM = SUMM+RMN(I)
        IF (I.GT.5) THEN
            SUMM = SUMM + RMN(I)
            RMN(I+3) = RMN(I)
        ENDIF
10   CONTINUE
    DO 15 I = 12,13
        RMN(I) = 4.0/3.0*PI*AN(I)*BN(I)*CN(I)*DENS
        SUMM = SUMM+2.*RMN(I)
15   RMN(I+2) = RMN(I)

C THE FOLLOWING ADJUSTS SEGMENT MASSES TO TOTAL BODY WEIGHT
C
    WTCCR = DD(0)/SUMM/GRAV
    DO 20 I=1,15
        RMN(I)=RMN(I)*WTCCR
20   CONTINUE
    RETURN
END

C--SUBROUTINE SGINGER-----[  

C   SGINGER COMPUTES SEGMENT MOMENTS OF INERTIA.  

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SUBROUTINE SGINER
EXTERNAL TORSO, FEET
COMMON /FLOAT/ PI,PI2,PI4
COMMON /SGMNTS/ AN(15),BN(15),CN(15),RMN(15),PHI(3,15)

      DO 5 I=1,3
      CALL ELLPMI (I,TORSO,PHI(1,I))
      DO 10 I=4,7
      TEMP=RMN(I)/5.0
      A2=AN(I)*AN(I)
      B2=BN(I)*BN(I)
      C2=CN(I)*CN(I)
      PHI(1,I)=TEMP*(B2+C2)
      PHI(2,I)=TEMP*(A2+C2)
      PHI(3,I)=TEMP*(A2+B2)
      IF (I.GT.5) THEN
      DO 7 J = 1,3
      PHI(J,I+3) = PHI(J,I)
      ENDIF
10  CONTINUE
      DO 20 I=12,13
      TEMP=RMN(I)/5.0
      A2=AN(I)*AN(I)
      B2=BN(I)*BN(I)
      C2=CN(I)*CN(I)
      PHI(1,I)=TEMP*(B2+C2)
      PHI(2,I)=TEMP*(A2+C2)
      PHI(3,I)=TEMP*(A2+B2)
      DO 15 J = 1,3
      PHI(J,I+2) = PHI(J,I)
15  CONTINUE
      CALL ELLPMI (11,FEET,PHI(1,11))
      DO 25 J=1,3
      PHI(J,8) = PHI(J,11)
      RETURN
      END

--SUBROUTINE ELLIP-----
C      ELLIP COMPUTES MASS AND CENTER OF GRAVITY LOCATION CF A RIGHT      C
C      ELLIPTICAL SOLID.  THE PARAMETERS ARE:                          C
C      ISEG--SPECIFIES SEGMENT BEING MODELLED BY RIGHT ELLIPTICAL SOLID   C
C      ABEVAL--SPECIFIES SUBROUTINE TO BE USED TO COMPUTE SEMIAXES OF THE   C
C      THE SOLID AT SPECIFIC Z HEIGHTS.                                C
C      TMASS--RETURNS THE MASS COMPUTED FOR THE SOLID.                  C
-----C

SUBROUTINE ELLIP (ISEG,ABEVAL,TMASS)
COMMON /CYL/ ZEES(0:15),ZH(15),NSEG(15),CGZ(15),TCOR
COMMON /FLOAT/ PI,PI2,PI4,DENS,GRAV
REAL IXX,IXXP,IYY,IYYP,IZZ,IZZP
REAL MASS
REAL MI(3)
TMASS=0.0
Z0 = ZEES(ISEG-1)
Z1 = ZEES(ISEG)
NSEG(ISEG)=0.0
10  NSEG(ISEG)=NSEG(ISEG)+1
TCGN=0.0
TMASS=C.0
ZH(ISEG)=(Z1-Z0)/FLOAT(NSEG(ISEG))
DO 100 I=1,NSEG(ISEG)
Z = Z0 + (FLOAT(I-1)+.5)*ZH(ISEG)
CALL ABEVAL(Z,A,B)

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MASS=PI*A*B*ZH(ISEG)*DENS
CG=Z
CGN=CG+MASS
TMASS=TMASS+MASS
100 TCGN=TCGN+CGN
TMASSN=TMASS
IF (ABS(TMASSN-TMASSO)/TMASSN.GT.5.E-5) THEN
TMASSC = TMASSN
GOTO10
ENDIF
CGZ(ISEG)=TCGN/TMASS
RETURN

C ENTRY ELLPMI
C ELLPMI COMPUTES MOMENTS OF INERTIA OF A RIGHT ELLIPTICAL SOLID, BASED
C ON THE NUMERICAL INTEGRATION DETERMINED BY ELLIP. THE FIRST TWO
C PARAMETERS ARE THE SAME AS THOSE USED BY ELLIP. THE THIRD, MI,
C RETURNS THE MOMENTS OF INERTIA OF THE SOLID.

ENTRY EL PMI (ISEG,ABEVAL,MI)
DO 5 I=1,3
5 MI(I)=0.0
Z0 = ZEES(ISEG-1)
DO 200 I=1,NSEG(ISEG)
Z = Z0 + (FLOAT(I-1)+.5)*ZH(ISEG)
CALL ABEVAL(Z,A,B)
MASS=PI*A*B*ZH(ISEG)*DENS*WTCOR
IXX=(MASS/12)*(3.0*B**2+ZH(ISEG)**2)
IYY=(MASS/12)*(3.0*A**2+ZH(ISEG)**2)
IZZ=(MASS/4.0)*(A**2+B**2)
DIST=Z-CGZ(ISEG)
IXXP=IXX+MASS*DIST**2
IYYP=IYY+MASS*DIST**2
IZZP=IZZ
MI(1)=MI(1)+IXXP
MI(2)=MI(2)+IYYP
MI(3)=MI(3)+IZZP
200 Z=Z+ZH(ISEG)
RETURN
END

C--SUBROUTINE TORSO-----
C TORSO COMPUTES SEMIAxis VALUES FOR THE RIGHT ELLIPTICAL MODEL OF THE C
C THREE TORSO SEGMENTS. THE PARAMETERS ARE THE FOLLOWING: C
C Z--VERTICAL LOCATION AT WHICH THE SEMIAxes ARE TO BE COMPUTED C
C X--RETURNS X SEMIAxis C
C Y--RETURNS Y SEMIAxis C
-----C

SUBROUTINE TORSO (Z,X,Y)
COMMON /DIMS/ D(-1:31)
COMMON /FLOAT/ PI,PI2
REAL H2,H3,H4,H5,H6

C H2--TOP OF SOLID
C H3--BREAK BETWEEN TOP SEMI-ELLIPSOID AND TOP FRUSTRUM
C H4--BREAK BETWEEN TWO FRUSTRUM
C H5--BREAK BETWEEN BOTTOM FRUSTUM AND BOTTOM SEMI-ELLIPSOID
C H6--BOTTOM OF SOLID

H2=D(2)
H3=D(3)
H4=D(4)
H5=(D(1)-D(5))+D(24)/PI2

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H6=(D(1)-D(5))
IF (Z.LT.H4)THEN
  IF (Z.LT.H6)THEN
    IF (Z.LT.H6)STOP 'Z IS LESS THAN MIN.'
    Y= SQRT(1. - ((Z - HS)/D(24)/PI2)**2)
    X = D(15)/2.*Y
    Y = D(16)/2.*Y
  ELSE
    Y=(Z-D(4))/(H5-D(4))
    X = (Y*(D(15)-D(13)) +D(13))/2.
    Y = (Y*(D(16)-D(14)) +D(14))/2.
  END IF
ELSE
  IF(Z.LT.H3)THEN
    Y=(Z-D(3))/(D(4)-D(3))
    X = (Y*(D(13)-D(11)) +D(11))/2.
    Y = (Y*(D(14)-D(12)) +D(12))/2.
  ELSE
    IF (Z.GT.H2) STOP 'Z IS GREATER THAN MAX.'
    Y=SQRT(1. - ((Z - D(3))/(D(2) - D(3)) )**2)
    X = Y*D(11)/2.
    Y = Y*D(12)/2.
  END IF
END IF
END

C--SUBROUTINE FEET-----C
C   FEET COMPUTES SEMIAxis VALUES FOR THE RIGHT ELLIPTICAL MODEL OF THE C
C   FEET. THE PARAMETERS ARE THE FOLLOWING: C
C   Z--Z LOCATION (TOE TO HEEL) AT WHICH SEMIAxes ARE TO BE COMPUTED C
C   X--RETURNS X SEMIAxis C
C   Y--RETURNS Y SEMIAxis C
C-----C

SUBROUTINE FEET (Z,X,Y)
COMMON /CYL/ ZEES(0:15),ZH(15),NSEG(15),CGZ(15),WTCOR
COMMON /DIMS/ DD(-1:31)
COMMON /FLOAT/ PI,PI2

C   H2--TOP OF SOLID
C   H1--BREAK BETWEEN ELLIPTICAL CYLINDER AND FRUSTUM
C   HO--90TCH OF SOLID

ANKR = DD(29)/PI2
H2 = DD(29) + ANKR
H1 = DD(29) - ANKR
HO = H2 - DD(31)

IF (Z.GT.H1) THEN
  IF (Z.GT.H2) STOP 'Z VALUE TOO LARGE IN FEET'
  X = ANKR
  Y = ANKR
ELSE
  IF (Z.LT.HO) STOP 'Z VALUE TOO SMALL IN FEET'
  X = ANKR/(DD(31) - 2.*ANKR)*(Z - DD(29) + DD(31) - ANKR)
  Y = (ANKR - DD(30)/2.)/(DD(31) - 2.*ANKR)
  Y = Y*(Z - DD(29) + ANKR) + ANKR
ENDIF

RETURN
END

C--SUBROUTINE RESULTS-----C
C   RESULTS WRITES OUT THE COMPUTED BODY DESCRIPTION DATA. C
C-----C

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SUBROUTINE RESULTS (ISTRRT)
COMMON /SGMNTS/ A(15),B(15),C(15),RMN(15),PHI(3,15),
3           XCG(15),YCG(15),ZCG(15)
COMMON /JNTS/ RNJ(3,16,2),JNT(14),YPRLL(14,6),IPIN(14)
COMMON /DIMS/ DO(-1:31)
COMMON /NAMES/ SUBTYP(4),SEGLAB(15),JNTLAB(14),PLTSYM(29),
3           DIMLAB(-1:31),TITLE,UNITS(3,-1:2)
COMMON /CYL/ ZEES(0:15),ZH(15),NSEG(15),CG2(15),WTCCR
CHARACTER SUBTYP*20,SEGLAB*3,JNTLAB*2,PLTSYM*1,DIMLAB*24,TITLE*60
CHARACTER ANS*1,UNITS*6,LABL1(2)*6,LABL2(2)*12,LABL3(2)*2,
6           LABL4(2)*4 ,VARB*6
DATA LABL1/LABL2/LABL3/LABL4 /'WEIGHT','MASS','LB-SEC**2-IN',
3   'KG-M**2','IN','CM','LBS.','KG','/ ,VARB/'OUTPUT'/
DATA IBET/201000000/, IA/240000000/

      WRITE (9,11)
      CALL ASKUN (VARB,UNITS(1,2),IUN,2)
      CALL CNVRT (IUN)
      IF (ISTRRT.LT.0) WRITE (9,22) -1,DIMLAB(-1),DD(-1),UNITS(1,-1)
      WRITE (9,22) 0,DIMLAB(0),DD(0),UNITS(IUN,0)
      WRITE (9,22) (I,DIMLAB(I),DD(I),UNITS(IUN,1),I=1,31)
      WRITE (9,66) WTCCR

      WRITE (9,44) '1'//TITLE
      WRITE(9,1170) LABL1(IUN),LABL2(IUN),LABL3(IUN),LABL3(IUN),
3           LABL4(IUN)
      WRITE(9,1180) (I,SEGLAB(I),PLTSYM(I),RMN(I),(PHI(J,I),J=1,3),
3           A(I),B(I),C(I),XCG(I),YCG(I),ZCG(I),I=1,15)
      WRITE(9,1190) LABL3(IUN),LABL3(IUN)
      WRITE(9,1200) (I,JNTLAB(I),PLTSYM(I+15),JNT(I),IPIN(I),
3           ((RNJ(J,I,K),J=1,3),K=1,2),(YPRLL(I,J),J=1,6),I=1,14)

10     WRITE (5,33)
      READ (7,44) ANS
      IF (ANS.EQ.'Y') THEN
        WRITE (3,77) TITLE(1:52)
        WRITE(3,1300) (SEGLAB(I),PLTSYM(I),RMN(I),(PHI(J,I),J=1,3),
3           A(I),B(I),C(I),XCG(I),YCG(I),ZCG(I),IA+I*IBET,I=1,15)
      C
        WRITE(3,1320) (JNTLAB(I),PLTSYM(I+15),JNT(I),IPIN(I),
3           ((RNJ(J,I,K),J=1,3),K=1,2),IA+I*IBET,
3           (YPRLL(I,J),J=1,6),I=1,14)
      ELSE
        IF (ANS.NE.'N') GOTO 10
      ENDIF

20     WRITE (5,55)
      READ (7,44) ANS
      IF (ANS.EQ.'N') STOP 'FROM RESULTS'
      IF (ANS.NE.'Y') GOTO 29
      RETURN

11     FORMAT ('-COMPUTED BODY DIMENSIONS')
22     FORMAT (I10,A30,G15.4,A6)
33     FORMAT (' IS ATB MODEL FORMATTED OUTPUT DESIRED (Y/N) ?')
44     FORMAT (A)
55     FORMAT (' IS IT DESIRED TO PRODUCE ANOTHER BODY DESCRIPTION ',
3           'DATA SET (Y/N) ?')
56     FFORMAT ('WEIGHT CORRECTION FACTOR =',F10.3)
77     FORMAT (4X,'15',4X,'14',8X,A52,'CARD 3.1')
1170 FORMAT (1H0,"CRASH VICTIM PARAMETERS (3-D)"/1H0,33X,
1 25HSEGMENT MOMENT OF INERTIA,
2 19X,25HSEGMENT CONTACT ELLIPSOID/5X,7HSEGMENT,7X,A6

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3,15X,'('',A12,''),17X,10HSEMIAXIS ('',A2,''),14X,'CENTER ('',
4,A2,'')/3X,12HNO. SYM PLOT,4X,'('',A4,''),10X,1HX,10X,1HY,1GX,
5HZ,12X,1HX,6X,1HY,6X,1HZ,12X,1HX,7X,1HY,6X,1HZ/1H )
1180 FORMAT ((3X,I2,2X,A4,A2,6X,F6.3,3X,3(4X,F7.5),5X,3(2X,F5.2),5X,3
1(3X,F5.2)))
1190 FORMAT(1H0,///3X,SHJOINT,16X,'LOCATION('',A2,'') - SEG(JNT)',5X,
1 'LOCATION('',A2,'') - SEG(J+1)',2X,'PRIN. AXIS(DEG) - SEG(JNT)',5X,
2 ' PRIN. AXIS(DEG) - SEG(J+1)'//2X,'J SYM PLOT JNT PIN',
3 4X,2(1X,'X',8X,'Y',8X,'Z',8X),2('YAW',5X,'PITCH',5X,'ROLL',6X)//)
1200 FORMAT ((I3,A6,A3,2X,2I3,4(3F9.2,1X)))
1300 FORMAT(A4,A2,F6.3,3F6.4,6F6.3,6X,'CARD 8.2.',A1)
1320 FORMAT(A4,1X,A1,2I6,6F6.2,22X,'CARD 9.3.',A1/14X,6F6.2)
END
C--SUBROUTINE CNVRT-----
C      CNVRT CONVERTS ALL OUTPUT DATA TO THE UNITS SELECTED BY THE USER
C-----C
SUBROUTINE CNVRT (IUN)
COMMON /SGPNTS/ ABC(15,3),RPN(15),PHI(3,15),XYZCG(15,3)
COMMON /JNTS/ RNJ(3,28)
COMMON /DIMS/ DD(-1:31)
REAL CONV(2,3)
DATA CONV /1.,2.54,32.17405,14.5939,12.,105.6034/

DO 100 I = 1,15
  DO 10 J = 1,3
    ABC(I,J) = ABC(I,J)*CONV(IUN,1)
    XYZCG(I,J) = XYZCG(I,J)*CONV(IUN,1)
10   PHI(J,I) = PHI(J,I)/CONV(IUN,3)
100  RMN(I) = RMN(I)*CONV(IUN,2)

DO 200 I = 1,28
  DO 200 J = 1,3
200  RNJ(J,I) = RNJ(J,I)*CONV(IUN,1)

IF (IUN.GT.1) THEN
  DD(C) = DD(0)/CONV(1,2)*CONV(2,2)
  DO 300 I=1,31
300  DD(I) = DD(I)*CONV(2,1)
ENDIF

RETURN
END

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